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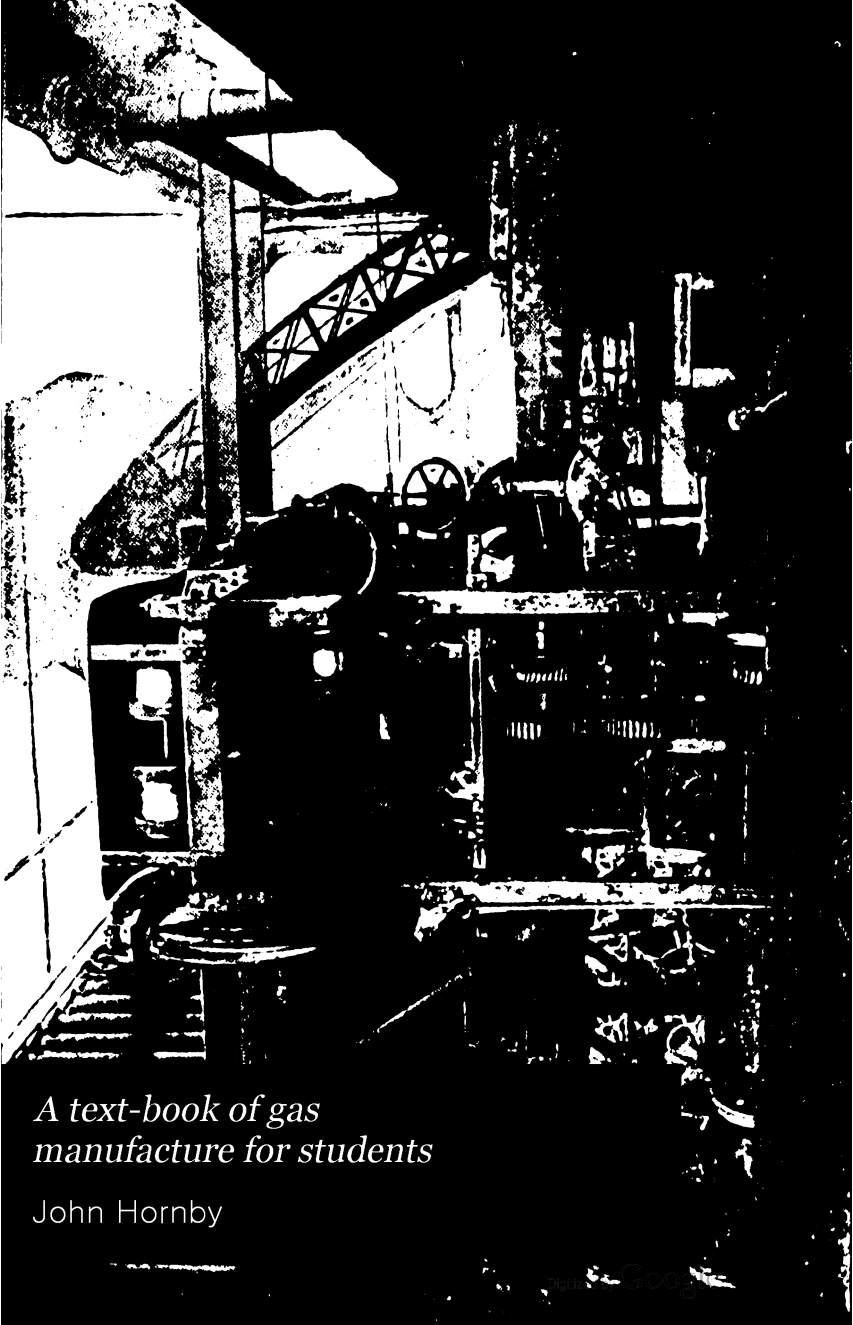
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*A text-book of gas
manufacture for students*

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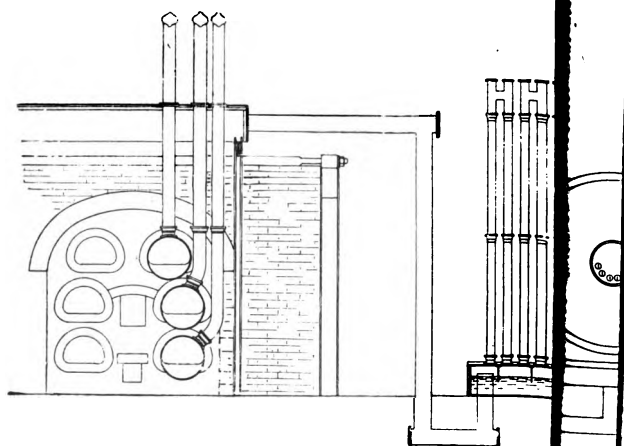
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GAS MANUFACTURE

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TECHNOLOGICAL HANDBOOKS.

A TEXT BOOK
OF
GAS MANUFACTURE
FOR STUDENTS.

BY

JOHN HORNBY, F.I.C.

HONOURS MEDALLIST IN GAS MANUFACTURE;
LECTURER ON GAS MANUFACTURE TO THE BARKING TECHNICAL
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AUTHOR OF "THE GAS ENGINEER'S LABORATORY HANDBOOK."



LONDON
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1900

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First Published, 1896.

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THIS LITTLE WORK IS DEDICATED
BY PERMISSION,
TO
THOMAS NEWBIGGING, ESQ., M.I.C.E.,
IN RECOGNITION OF HIS EMINENT SERVICES TO THE LITERATURE
OF GAS MANUFACTURE.

P R E F A C E.

THE object of this little work is to provide a manual of gas manufacture suitable to the requirements of young men just starting their training in a gas-works, which shall also serve as a text book for the use of students who are preparing for the examinations of the City and Guilds of London Institute in the subject of gas manufacture. Although there are several excellent treatises on gas manufacture already in existence, I have found in my capacity as lecturer under the City and Guilds, the want of a small book which should just cover the ground included in the syllabus on which the examinations of that body are based, and the present volume has been written with the view of meeting this want. I trust, therefore, that the book will be of service to others engaged in the teaching of the subject.

It will be noticed that I have not touched on the various quantitative chemical tests required in gas-works; my reasons for omitting the same being that in the first place the space at my disposal would not have allowed me to treat the subject in the exhaustive manner necessary to make it clear to a beginner, and, secondly, because I have already gone into the subject very fully in my "Gas Engineer's Laboratory Handbook" (Spon and Co.), to which the student is referred.

I have to express my thanks to Professor Lewes for his kindness in allowing me to make free use of his many ex-

cellent papers in connection with gas manufacture, and to Messrs. R. Dempster and Co., of Manchester; Cowan and Co.; West's Gas Improvement Co., Gwynne and Co., C. and W. Walker, and Kirkham and Hersey, for the loan of blocks and for information concerning their various specialities. I have not hesitated to avail myself of the classical writings on gas topics of Messrs. Charles Hunt, T. Newbigging, and L. T. Wright, and have also to acknowledge my indebtedness to the following list of works which have been consulted in the preparation of this volume, and which are recommended to the student for fuller details concerning many of the points herein touched upon:

Bowditch, "The Analysis, etc., of Coal-Gas." (Spon and Co.)

Graham's "The Construction and Working of Regenerator Furnaces." (Spon and Co.)

Hartley's "Gas Analysts' Manual." (Spon and Co.)

Herring's "The Construction of Gas-Works." (Hazell, Watson, and Viney.)

Hughes on "Coal-Gas." Revised by Richards. (Crosby, Lockwood and Co.)

Jones, "Sound, Light, and Heat." (Macmillan and Co.)

Mackenzie's "Chemistry as Applied to the Arts, etc." (Mackenzie.)

Newbigging's "Gas Manager's Handbook." (King.)

The excellent articles on "Coal-Gas" in Vols. 59, 60, 61, and 62 of the "Journal of Gas Lighting." (King.)

The lectures on "Coal-Gas" by Mr. C. Hunt, reported in Vol. 51 of the "Journal of Gas Lighting."

The lectures on "Coal-Gas," by Mr. L. T. Wright, reported in the "Journal of Gas Lighting."

In addition to the above the student will find much valuable information in the following:

Butterfield's "The Chemistry of Gas Manufacture."
(Griffin.)

Cripps' "The Guide Framing of Gas-holders." (King.)

Dibdin's "Practical Photometry." (King.)

"Gas-burners, Old and New." (King.)

Humphrys, "The Chemistry of Illuminating Gas."
(King.)

King's "Treatise on Gas Manufacture." 3 vols. (King.)

The article on "Coal-Gas," contributed by Mr. L. T.

Wright to Thorpe's "Dictionary of Applied Chem-
istry." (Longmans.)

The "Journal of Gas Lighting."

J. H.

BECKTON,

December, 1895.

CONTENTS.

	PAGE
INTRODUCTION.	1
CHAP.	
I. The Characteristic Properties of the Various Kinds of Coal, and their Value for Gas-making Purposes	4
II. Carbonization	14
III. The Description and Arrangement of Apparatus employed for the Conveyance of the Gas immediately upon its leaving the Retorts	35
IV. Labour-Saving Appliances in the Retort-House, and in the Working of Retorts.	43
V. The Effects of Temperature in Modifying the Quantity and Quality of the Gas produced	52
VI. The Effects of Temperature upon the Production of Residuals	60
VII. Purification (<i>Condensation</i>)	67
VIII. The Exhauster	77
IX. Purification (<i>Abstraction of the Ammonia</i>)	86
X. Purification (<i>Elimination of CO₂, SH₂, and CS₂</i>)	109
XI. The Simplest Methods of Ascertaining the Purity and Illuminating Power of Gas	127
XII. A Description of the Various Instruments used in Gas-Works for Ascertaining and Recording Pressure and Exhaust	133
XIII. The Gas-holder and its Tank	139
XIV. The Practice of Photometry	153
XV. The Methods employed for Controlling Pressure at the Works so as to secure an adequate supply of Gas at the various points of Consumption, with a due regard for Economical Effect	175

CHAP.	PAGE
XVI. The Laying of Mains and Service Pipes . . .	185
XVII. The Construction of Gas Meters . . .	203
XVIII. Gas Burners . . .	217
XIX. Influence of Temperature and Pressure upon the Volume of Gas . . .	227
XX. The Composition of Coal-Gas . . .	233
XXI. The Enrichment of Coal-Gas . . .	242
XXII. The Manufacture of Sulphate of Ammonia . .	249
APPENDIX :	
The Referee's Sulphur Test . . .	252
Spent Oxide of Iron Test . . .	254
Specimen Examination Papers of the City and Guilds of London Institute in Gas Manufacture . . .	256
INDEX . . .	261

LIST OF PLATES.

	PAGE
FRONTISPIECE.	
TOOLS EMPLOYED IN THE RETORT-HOUSE	34
PATENT "STANDARD" WASHER-SCRUBBER. . . .	106
WATER-GAS PLANT	244
PEEBLES OIL-GAS PLANT	246
SULPHATE OF AMMONIA PLANT	250

A TEXT-BOOK OF GAS MANUFACTURE FOR STUDENTS.

INTRODUCTION.

IT will be advisable at the outset, to give a brief general sketch of what goes on in a gas-works, as this will greatly help the student in grasping the connection between the various apparatus which go to form a gas-making plant. The latter is shown in the frontispiece.

In the manufacture of coal-gas, as ordinarily practised, bituminous coal is placed in charges of from two to four hundredweights at a time, in fire-clay vessels termed retorts, capable of being hermetically sealed, and which have been previously heated, by means of a furnace, to a suitable gas-making temperature. The charge is allowed to remain in the retorts for a period of from four to six hours, at the expiration of which time the coal will have given off all the gas it is capable of evolving, and have become converted into coke.

The gas as it comes from the retorts passes up through a pipe leading from the mouthpiece, known as the ascension pipe, and is conducted by this into what is known as the hydraulic main, where a portion of the tarry matters become deposited. The hydraulic main extends along the whole length of the retort benches, receiving the dip pipes of the several benches of retorts.

The hydraulic main serves a twofold purpose; it acts, in the first place, as a means of conveying away the gas from the place where it is generated; and, in the second place, it acts as an automatic contrivance for sealing the dip pipes, as they are termed, and thus preventing any escape of gas during the charging and drawing of the retorts; this is effected by keeping the hydraulic main always about half full of liquid, and allowing the dip pipes to "dip" a short distance in the same. From the hydraulic main the gas travels to the condensers, where, by traversing a series of pipes exposed to the cooling action of the air, the gas becomes cooled, and deposits the tar and aqueous vapour previously held in suspension.

The tar and condensed aqueous vapour deposited by the action of the condensers, are run off by a suitable pipe into a receptacle known as the "tar well," the capacity of which depends upon the amount of coal carbonized. From the condenser the gas passes to the exhauster, the function of the last-mentioned piece of apparatus being, to remove the gas from the heated retorts as fast as it is produced, and, at the same time, to propel it onward with sufficient force to enable it to pass through the materials used in its purification, and from thence to the holder. It is necessary to remove the gas from the retorts as quickly as possible, for two reasons; both of which depend upon the injurious effect caused by the gas being subjected to excessive pressure in the retorts, which operates prejudicially, both by causing a partial decomposition of the richest portions of the gas, with a consequent loss of illuminating value, and also by causing leakage through the porous walls of the retort.

From the exhauster the gas enters the apparatus intended for the abstraction of the ammonia in the same, consisting usually of the scrubber or washer, or a combination of the two; the last-mentioned apparatus in this case being placed first.

The function of both the scrubber and washer, is the removal of the whole of the ammonia and some portion of the carbonic acid and sulphuretted hydrogen contained in the gas, which is effected in the case of the washer, by bubbling it through water, and in that of the scrubber, by bringing the gas into contact with a large extent of surface kept wet by water. From the scrubbers the gas passes to the vessels known as the purifiers, which are filled with lime and oxide of iron, by whose action the remaining impurities, consisting of carbonic acid and sulphuretted hydrogen, are got rid of, the gas being then in a sufficiently pure condition to be supplied to the consumer.

From the purifiers the gas passes to the station meter, where the amount of gas being made is registered, and from thence it enters the gas-holders, where it is stored for use.

From the holder the gas passes to the district for consumption, the necessary pressure being regulated by a piece of apparatus known as the station governor, placed at the outlet of the holder.

CHAPTER I.

THE CHARACTERISTIC PROPERTIES OF THE VARIOUS KINDS OF COAL, AND THEIR VALUE FOR GAS-MAKING PURPOSES.

WHEN vegetable matter decays, in absence of air, it undergoes a similar change as when it is heated. Water, CO_2 , and marsh-gas are given off, and the material remaining becomes richer in carbon; the fact that CO_2 and CH_4 are among the products of decomposition from vegetable matter, is proved by the last-named substances being found in a highly compressed condition in the coal-measures of the present day; and it is the marsh-gas, or so-called fire-damp, which causes the colliery explosions with which we are unfortunately so familiar. It is by the decomposition of decaying vegetable matter that the various kinds of coals, lignites, and peats have been formed.

The conversion of the vast mass of vegetable matter from which coal is derived, into the latter substance, has been the work of ages, but the exact causes, chemical and physical, which have brought about this change are unknown. It is probable, however, that the first change would be the loss of moisture, and the fermentation of albuminous matter and gum. This would bring about a molecular change; there would be a rise in temperature, but an absence of a supply of air would check too rapid carbonization.

The mass of vegetation, it must be recollected, would at this time be also subjected to great pressure. The oxygen and hydrogen being most subject to the effect of this

metamorphosis—these elements leaving the carbon—would more readily assume their simplest and more permanent state of combination. But conditions of temperature and pressure complicate the reaction, with the result that CO_2 and hydrocarbons of the marsh-gas series are formed, leaving an accumulation of carbon and mineral matter in the residue.

Now the bulk of woody fibre (the substance of which the vegetable deposits were chiefly composed) is known as cellulose, and the formula of this substance is $\text{C}_6\text{H}_{10}\text{O}_5$, and we can represent the complete reaction of the fermentation and decay of this substance by the following equation :

Woody fibre.



This theory is supported by the fact already alluded to, that these two gases, CO_2 and CH_4 , are found in the coal-seams of the present day.

The most complete conversion of woody fibre into carbon is seen in the substance known as graphite or "black-lead," while intermediate stages in the decomposition yield lignite, bituminous coal, and anthracite.

The gradual conversion of woody fibre into peat, coal, and graphite is shown in the following table :¹

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Wood	50·00	6·00	44·00
Irish peat	60·02	5·88	34·10
Lignite from Cologne	66·96	5·25	27·76
Earthy coal from Dax	74·20	5·89	19·90
Cannel coal from Wigan	85·81	5·85	8·34
Newcastle Hartley	88·42	5·61	5·97
Welsh anthracite	94·05	3·38	2·57
Graphite	100·00	0·00	0·00

¹ Roscoe and Schorlemmer, "Treatise on Chemistry," vol. i., p. 576.

Now coals may be broadly classed into three principal varieties, viz., lignite, bituminous coal, and anthracite, and these are examples of the material cellulose or woody fibre, in different stages of carbonization or decomposition. "Brown coal or lignite belongs to a different and more recent geological period than coal proper, being found in the tertiary formation. It consists of the remains of trees and shrubs, as ash, poplar, and others which exist at the present time upon the surface of the earth. It possesses a brown colour, and often exhibits a characteristic woody structure. Its specific gravity varies from 1.15 to 1.30. Earthy brown coal is another brown friable material, sometimes forming layers in beds of lignite, but it is not a true coal, inasmuch as a considerable portion of it is soluble in ether and benzine, and often even in alcohol, whereas true coal is nearly if not quite insoluble in these liquids." Lignite contains a larger amount of hydrogen than any other variety of coal, and it is consequently more easy to ignite, and burns with more flame than any of the other varieties.

Common lignite is of interest to the gas manufacturer by reason of its strong resemblance to coal, for which it might easily be mistaken. Anthracite belongs to the oldest coal formations. In its purer form it consists of little else than carbon, water, and mineral matter, and represents the last stage of the coal-forming process. It has a high degree of lustre, but is not suitable for gas-making.

Anthracite is found in large quantities in America, and in this country it is found in the South Wales coal-field. The following is an analysis of Welsh anthracite:

	Per cent.
Fixed carbon	89.84
Ash	1.20
Sulphur	0.80
Moisture	2.25
Volatile matter	6.01

The bituminous coals consist of a large number of varieties, differing considerably from one another in their chemical composition, as also in their products of decomposition by heat. They have the common property of burning with a smoky flame when placed in the fire, and yielding, on distillation, volatile hydrocarbons, tar or bitumen, whence their name is derived. Coal-gas is usually obtained from bituminous coals.

Bituminous coals are generally found in secondary formations; the most marked varieties being caking coal, splint coal, cherry coal, and cannel coal. Of the above varieties, caking coal is the one which is most used as a gas producer. It is found in almost all English coal-fields, but the Northumberland and Durham districts are the most noted producers. This variety of coal is moderately compact, and possesses a lustre which varies from a resinous to a velvety or greyish-black appearance. Its specific gravity is usually about 1.25. It derives its name, "caking coal," from the fact that on the application of heat it melts and cakes (or cokes) together into a pasty mass.

Splint, or hard coal, is that dull coal which is often found mixed with samples of caking coal, and which seems to have the property of preventing the charge from swelling in the retort. Splint coal is found in the coal-measures in the vicinity of Glasgow; its colour varies from black to a brownish-black.

Cherry coal is very similar in appearance to caking coal; it is, however, more brittle, and does not fuse on heating, each piece of coke retaining the shape of the original coal. Cherry coal is found in the upper strata of the Glasgow coal-beds, and also in the Staffordshire and Lancashire district. Cannel coal is also known as "parrot coal," and is found in Scotland, Lancashire, Warwickshire, and North Wales, and is greatly prized for its gas-producing qualities, as the different kinds of cannel yield varying quantities of

gas, ranging from 10,000 to 15,000 cubic feet of gas per ton, of a quality of from 20 to 45 or 50 candles. As a rule the coke from cannel is inferior to that produced by common coals, although this distinction cannot always be sharply drawn. The Wigan cannel, for instance, yields a coke similar to that from "caking coal;" it is therefore called "caking cannel."

"In the term cannel are included many kinds of coal, the extreme members of which offer more differences in practical results than the other class of coals. Broadly classed under this head are all hard, non-laminated coals having a homogeneous character. When having a flaky fracture and an earthy appearance, it is often called shale.

"For gas-manufacturing purposes all hard coals, homogeneous in appearance, and yielding gas of 20 candle-power, and upwards, are classed as cannels. The richer descriptions are dull and brown; the poorer, or secondary cannels, are generally bright and black; the third class, producing gas of a quality of about 20 candles, are dull and black. True cannels do not cake, but yield on distillation a similar residue (with the exception of some cracks and fissures) to coal. These cracks, however, indicate the laminated structure, which was not visible in the original cannel. (Any sample of coal will, on examination, be found either to consist of laminations of varying thickness and of different kinds of coal, or to be homogeneous in appearance, giving no sign of lamination or stratification.) The ash in cannel coals is greater than that in caking coals, and often shows the laminated structure more clearly than the coke.

"Cannel coals as a rule yield more tar, and of a lighter specific gravity, than caking coals.

"Whilst the physical difference between common coal and cannel is well marked, the same cannot be said of the

chemical differences between the various cannel and the caking coals; certain cannel having precisely the same elementary composition as some caking coals. In common cannel, yielding about 10,000 cubic feet of 21 candle gas per ton, the carbon is about 13 times as much as the hydrogen. In the highest members, such as Boghead, or Australian shale, the carbon is from 7·2 to 7·7 times the hydrogen. The structure of cannel is suggestive of its having been originally in a highly divided form as an organic mud, and it leaves on combustion an ash as bulky as the coal, the richest cannel generally containing most of this earthy admixture" (L. T. Wright).

The following tables give the chemical composition of some of these different varieties of coal:

Non-caking Bituminous Coals.

Locality.	Specific Gravity.	Car-bon.	Hydro-gen.	Oxy-gen.	Nitro-gen.	Sul-phur.	Ash.
South Staf-fordshire .	1·278	78·57	5·29	12·88	1·84	0·39	1·03
St. Helens, Lancashire	1·279	75·81	5·22	11·14	1·93	0·90	5·00

Caking Bituminous Coals.

Locality.	Specific Gravity.	Car-bon.	Hydro-gen.	Oxy-gen.	Nitro-gen.	Sul-phur.	Ash.
Northumber-land . .	1·276	81·41	5·83	7·90	2·05	0·74	2·07
„	1·259	78·69	6·00	10·07	2·37	1·51	1·36

Cannel Coals.

Locality.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Wigan . .	1·317	84·07	5·71	7·82	—	—	2·40
„ . .	1·276	80·07	5·53	8·08	2·12	1·50	2·70
Scotland . .	—	66·44	7·54	10·84	1·36	0·84	12·98
„ . .	—	63·10	8·91	7·25	—	0·96	19·78

When we subject coal to an elementary organic analysis we simply obtain the total amount of carbon, hydrogen, oxygen, nitrogen, sulphur, and ash which it contains, as given in the tables above, but we know little or nothing of the way in which these elements are combined. "There can be but little doubt, however, that it is correct to look upon it as carbon which contains, either mixed with it or combined with it, hydrocarbon compounds of much the same character as the paraffins, and also compounds of carbon, hydrogen, and oxygen, of somewhat similar kind to the woody fibre from which it has sprung, while other compounds containing nitrogen, and probably of more complexity, are also present."

This theory has been recently corroborated by an investigation conducted by Mr. W. M'Connell, of the Durham College of Science, and reported in the "Journal of Gas Lighting" for January 30th, 1894.

One piece of information which has an important bearing on the suitability of a coal for gas-making purposes is obtained from an elementary analysis of the same, viz., the percentage of unoxidized hydrogen, by which is meant hydrogen unaccompanied by an equivalent of oxygen, which is obtained by deducting one-eighth of the percentage of oxygen from the percentage of hydrogen.

According to Professor Wanklyn¹ coal is very poor for

¹ "Gas Engineers' Chemical Manual," p. 13.

gas-making purposes when the unoxidized hydrogen is less than four per cent., and it is exceedingly rich when the unoxidized hydrogen exceeds five per cent. The following is an example of what is meant.

Elementary Analysis of Newcastle Coal.

	Per cent.
Carbon	86.81
Hydrogen	4.96
Nitrogen	1.05
Sulphur	0.88
Oxygen	5.28
Ash	1.08
Unoxidized hydrogen	4.31

The reason why the percentage of unoxidized hydrogen plays such an important part in the choice of a coal is, that when the coal is carbonized, every 16 parts of oxygen present unite with 2 parts of hydrogen to form 18 parts of water, so that it is only the hydrogen over and above that required by the oxygen, that is available for the production of hydrocarbons.

In addition to an elementary analysis, much useful information relative to the suitability or non-suitability of any particular coal for gas-making purposes, may be obtained from a "proximate" analysis, which tells us the moisture, specific gravity, percentage of volatile matter, ash, and sulphur. The amount of moisture in coal is of importance. When Newcastle coal is carbonized, water is given off with the gas to the amount of about twelve gallons per ton, but the whole of this is not due to the chemical combination of the hydrogen and oxygen in the retort, but a portion of it (varying in the case of Newcastle coals from two to four gallons per ton) is due to the moisture held in mechanical combination by the coal. The presence of this moisture in

the retort is prejudicial for many reasons, as it reduces the heat of the retorts, increases the CO_2 in the gas, and liberates a portion of the sulphur, which would otherwise remain behind in the coke. The amount and nature of the ash, or clinker, is a very important factor in the choice of a coal. The ash in coal is purely inorganic, and generally consists of a variable mixture of silica, alumina, oxide of iron, and lime, the colour varying in Newcastle coals from a light cream to a brick red colour. The red colour is due to oxide of iron, which indicates the presence of iron pyrites, and consequently of much sulphur in the coal. Coals of this description, *i.e.*, coals yielding a red ash, destroy the furnace bars. Another important feature in the nature of the ash is whether a thick, pasty slag, or a thin, fluid slag is formed in the furnace. If a liquid clinker be the result, then the coke will be more easily worked in the furnace, and consequently be better adapted for keeping up the heats in the retorts.

The following is an analysis of the ash of a Newcastle coal as given in Newbigging's "Handbook :"

	Per cent.
Silica	59.56
Alumina	12.19
Peroxide of iron	15.96
Lime	9.99
Magnesia	1.13
Potash	1.17
	100.00

The sulphur which is always present in coal, exists in many forms, generally combined with iron in the form of iron pyrites, sometimes as CaSO_4 , and more rarely in combination with organic elements. In common coals the sulphur that is present in the form of iron pyrites alone

affects the gas manufacturer, and in this condition it is either invisible, or it is seen in the form of nodules, or in the yellow laminations known as "brasses."

The formula for iron pyrites is FeS_2 , and when it is heated in the atmosphere of hydrogen which exists in the retort, it loses half of its sulphur, which goes off into the gas as sulphuretted hydrogen (SH_2), carbon disulphide (CS_2), and other sulphur compounds; but if moisture is present to any extent in the coal, the water acts upon the other atom of sulphur and sets the latter free also. It should be noted that the sulphur in caking coals generally is found as iron pyrites, while the sulphur in cannel coal occurs in some organic form. This organically combined sulphur is nearly all expelled in the process of carbonization, and unites very readily with carbon at the temperature usually met with in the retort, to form the impurity CS_2 .

The amount of sulphur given off from a coal during distillation is not the same under all conditions, as it greatly depends upon the temperature at which the coal is distilled. It is with high heats, and at the end of the charge, that most of the sulphur, especially in the form of CS_2 , is given off. For an account of the gas-producing powers of the various descriptions of coal, the student should consult Newbigging's "Handbook," or King's "Treatise."

CHAPTER II.

CARBONIZATION

The construction of a retort or oven best adapted for the destructive distillation of coal—The setting of retorts and the construction of retort furnaces—The principles of combustion and their application to the working of retort-furnaces.

THE process by which gas is obtained from coal, is a chemical operation known as destructive distillation, and technically called carbonization. The chemical changes which occur during the destructive distillation of coal are both numerous and interesting, and as it is very necessary for those engaged in the manufacture of gas to have a correct knowledge of the nature of such changes, it will be advisable, before proceeding further, to say a few words concerning what takes place in the retort when the coal is destructively distilled.

The greater part of the hydrogen of the original coal passes off, partly in combination with oxygen as aqueous vapour (H_2O), and partly combined with carbon as marsh-gas (CH_4), and olefiant gas or ethylene (C_2H_4), together with smaller quantities of acetylene, benzol, and other hydrocarbons, while a portion passes off in the free state. The nitrogen of the coal is driven off, combined with hydrogen in the form of ammonia, and with carbon in the form of cyanogen; and the sulphur which is present in the original coal in the form of iron pyrites or "brasses," is evolved in two forms, viz., as sulphuretted hydrogen (SH_2), and as carbon bisulphide (CS_2), and according to some authorities as SO_2 .

Part of the aqueous vapour driven off from the coal is likewise decomposed by the action of carbon at a high temperature forming carbonic acid (CO_2), carbonic oxide (CO), and free hydrogen. As the various gases leave the retort, and the diminished temperature permits mutual chemical affinity to have more play, several of the substances previously alluded to re-combine. For example, the ammonia unites with a part of the H_2S , CO_2 , and SO_2 , and the cyanogen, to form the sulphhydrate, carbonate, sulphite, and cyanide of ammonium respectively, and these compounds again mutually react on each other, the ammonium cyanide and sulphide forming sulphocyanide; while another portion of the sulphide, under the influence of SO_2 , causes the hyposulphite of ammonium to be formed.

A portion of the carbon bisulphide also probably combines with free ammonia to form ammonium sulphocyanide.

The following table shows how the nitrogen present in the original coal is distributed after the latter has been destructively distilled.

	Per cent.
Nitrogen as ammonia	14.50
Nitrogen as cyanogen	1.56
Nitrogen free in gas and combined in tar .	35.26
Nitrogen remaining in coke	48.68
	100.00

The carbonization of the coal is the most important of all the operations which are carried on in a gas-works, the successful working of the concern entirely depending upon the results obtained in the carbonizing department, as the yield of gas per ton of coal, the amount of coke available for sale, and the cost of carbonizing labour are all factors which make a works profitable or not. If good results are

not obtained in the retort-house in the first instance, no amount of after care in the other departments of the works will have much effect.

The first essential for obtaining good carbonizing results, is to be able to heat the retorts in which the carbonization is effected, to the temperature which is necessary for the disengagement of the whole of the gas obtainable from the particular coal employed, with the use of the minimum amount of fuel, and in order to do this, it is necessary to pay especial attention to the retort settings; but, before proceeding to describe the setting of the retorts, it will be advisable to say a few words concerning the retorts themselves, the retorts being the vessels in which the destructive distillation is carried on.

Formerly, retorts made of cast-iron were employed, and they are still used in experimental plants, and in very small works where an exhauster is not in use. At the present time, however, retorts are almost universally made of fire-clay, as the latter material possesses the advantage over cast-iron of being cheaper, more durable, and more refractory; that is to say, it is capable of being heated to a higher temperature without injury. One of the most important revolutions in the gas industry, was the introduction of clay retorts in conjunction with the employment of the exhauster.

On the other hand, clay retorts possess the disadvantage that when once they are heated, they do not stand being let down like those made of cast-iron, as they invariably contract, and consequently crack when cooling.

The usual shapes in cross section of retorts employed are known as "the round," "the oval," and "the D-shaped," as shown in fig. 1.

The considerations to be kept in view in selecting a retort best adapted for the economical production of gas are, that the heat shall be capable of easily penetrating the mass of

coal in the interior; and, also, that the gas when generated shall not be liable to be too much exposed to the hot walls of the retort, by there being too much space between the level of the coal in the retort, when the latter is charged, and the crown of the vessel; consequently, of the shapes mentioned above, the one which best fulfils the conditions laid down is the shallow D, or a D with a slightly curved bottom,

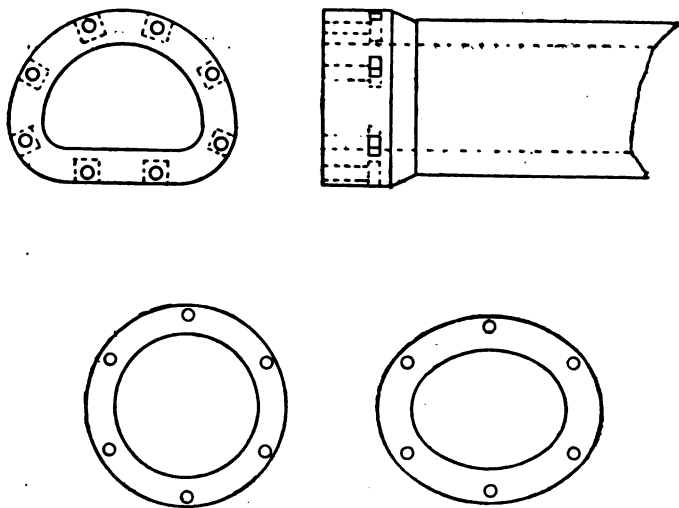


FIG. 1.

known as "the oval D." The "round" retort, owing to its shape, is the strongest, but is the least desirable form to be employed, as the coal cannot be placed in the same in a thin even layer.

Mr. Newbigging, in his "Gas Managers' Handbook," gives the following sizes (inside) of retorts as being useful and convenient:

Round, 15 inches diameter.

Oval, 21 × 15 inches.

D-shaped, 18 × 15 inches.

The D-shaped, 20 × 13 inches, is also a very useful size, while 22 × 16 inches is a convenient size where stoking machinery is employed. Clay retorts are usually made from $2\frac{3}{4}$ to 3 inches thick, the flange for attaching to the iron mouthpiece being 4 inches thick and 8 inches broad, the neck tapering gradually down to the thickness of the body of the retort.

Retorts are divided into two classes, "single" retorts, and "through" retorts.

Single retorts have one end closed, the other end having a mouthpiece, and are generally 9 to 10 feet long; a through retort has a mouthpiece at both ends, and is usually from 18 to 22 feet long. The advantages of using through retorts are, that in such retorts the accumulation of carbon is less, owing to the closed ends being absent; and, also, that the current of cold air which is drawn through the retort each time it is charged, helps to loosen any deposited carbon; and further, that more heating surface is available for the same expenditure of fuel, and that in the hottest portion of the setting. It is obvious however that through retorts are not suitable for very small works, as where the stokers are fewer than six in number. Retorts should be hard, well-baked, and glazed on their interior surface; they are generally put together in lengths varying from 4 or 5 feet to 10 feet, but some engineers prefer to construct them with a number of small pieces, or bricks, each separately moulded and burnt. These are put together and jointed with great care, so as to secure the required size and shapes. The average life of a clay retort may be taken as thirty working months, while an iron retort will only be capable of working twelve months.

Retorts are placed in arches made of fire-bricks, the size of the arch depending upon the number of retorts it is

intended to contain, which may vary from two to nine or more. The arch, with its retorts, is technically known as a bed, or setting.

The necessary essentials of a bench of retorts are the furnace for producing the heating gases; the main flue for carrying away the spent products of combustion; and the chimney for creating the necessary draught to draw away the spent products, and to draw in the necessary amount of air for the production of the heating gases.

The width of the arches in which the retorts are set depends upon the size of the retorts and their arrangement in the setting; the form of the arch also depends in some measure on the description of setting employed, as arches of an elliptical and segmental form allow of three retorts being placed in the top tier, where a semicircular arch would only permit of two being so placed. In erecting the retort bench it is necessary to have a good foundation, consisting of a bed of concrete two feet thick laid under the whole surface of the bench, and extending to a distance of from two to three feet beyond the outside walls, arrangements being made for thoroughly draining the ground should the latter happen to be of a damp nature.

It is necessary to make provision in the bed of concrete for the ash-pit, or generator, as the case may be, according as to whether the furnace will be of the ordinary direct-fired, or generator type. The level of the top of the concrete should be about three or four courses below the intended floor line, and at this level the division walls of the setting should be commenced; the division walls above the footings should be 18 inches thick, and the buttress walls at the two ends of the setting from two to three times that thickness. The floor of oven should be paved with two courses of fire-bricks set on edge and cemented with fire-clay.

The arch should be formed of three rings of $4\frac{1}{2}$ inches of fire-bricks, and should be arranged with a $4\frac{1}{2}$ -inch

reveal at the front, to enable the front wall of setting to cover instead of forming a straight joint. The top of the bench above the arches should be haunched up five courses with fire-bricks laid solid, and finished with one course on edge to form a coping, making the total height of the bench about 10 feet 6 inches from the floor line; these particulars of course referring to a ground-work retort house.

In the crown of the arch two flue-holes are formed, one for each furnace. These are usually 12 inches square, and situated at the back of the setting. On the top of the bench the main flue communicating with the chimney is constructed; this is divided in the middle, so as to form two flues, and is constructed of fire-bricks set in fire-clay; it is provided with dampers, which cover the two flue-holes in the furnace arch.

It was formerly the practice to have only one tall chimney-stack, which served for all the benches in the retort house, but it is now the common practice to erect dwarf chimneys, built on the top of the arches, and carried only a few feet above the ridge of the roof, one such chimney serving for a bench of six or eight settings.

"It is very important that the main flue and chimney should be of ample area, in order to ensure good working, and to ensure this the area should be about 40 superficial inches for each ton of coal carbonized by the bench of retorts for which it is constructed. Where one chimney serves a large bench of retorts, say of twelve settings, this figure may be reduced to 30 superficial inches per ton of coals carbonized" (Herring).

The whole of the brickwork forming the retort bench must be braced together by means of buckstays, tie-rods, etc., both longitudinally and cross-wise, in order to prevent any undue expansion that may be caused by the heat of the setting.

A suitable arrangement of buckstays is shown in fig. 2.

The arrangement consists of two flat wrought-iron bars, connected together at intervals by cast-iron distance pieces, and trussed as shown. One of these buckstays is placed at each end of the division wall of the setting, and is carried a few feet above the top of the retort bench, the tops of the buckstays being connected together by a wrought-iron joist, which not only acts as a tie, dispensing with the customary transverse tie-rods, but

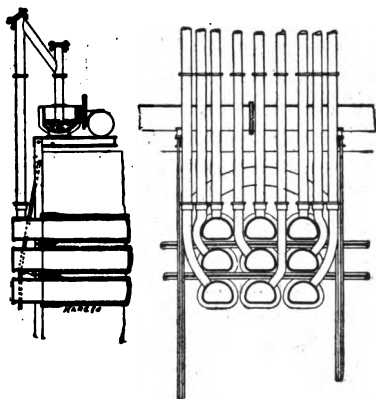


FIG. 2.

also serves to support the hydraulic main. The lower ends of the buckstays should be securely fixed in concrete to a depth of at least a foot. The end buckstays should be stronger than the front ones, on account of the greater thrust on the buttress walls, and generally consist of H-iron girders. There should be four buckstays fixed at each end buttress of the bench, not less than 12 inches deep. These buckstays are attached to longitudinal tie-rods, which run the full length of the bench; the tie-rods are of wrought-iron, 2 inches in diameter, divided into two or more lengths. The tie-rods are attached to the

H-iron buckstays, either by a flat iron strap, which fits over the top of the H-iron, and is welded to the tie-rod, or they are screwed for a distance of about 12 inches at their ends, and pass through a hole tapped to the same thread at the top of the buckstay, the projecting end being secured by a nut. Stretching screws and unions are employed for making the joints between the lengths of the tie-rods.

Fig. 4 is a longitudinal section of a bench of "through" retorts, showing the "furnace," "the arch," and the connection with the main flue.

The methods of setting and heating retorts employed by different engineers necessarily vary, but the following brief description of one method, with the aid of fig. 3, should make the subject tolerably clear.

As will be seen, the retorts are placed in an arch horizontally, within a few inches of each other. Situated in the centre, below the level of the bottom retorts, is a furnace, which may be described as a rectangular fire-brick chamber with an arched top, and having an iron door for the purpose of charging with fuel. The furnace is open at the bottom, which is provided with fire-bars, on which rests the fuel, the air necessary for the combustion of the latter, passing through the spaces between the bars.

The furnace arch is made with openings at certain intervals so as to allow the heating gases to pass into the setting, such openings being known as "nostrils."

The retorts are supported on fire-brick walls, which are formed by carrying up the brickwork corresponding to the solid portion of the furnace arch, so that there is alternately a solid wall and a hollow space corresponding to the nostril holes in the furnace arch; the walls are also provided with openings which communicate with the hollow spaces at intervals, so that the heating gases circulate in every direction round the retorts, the arrangement described answering the purpose of a series of flues. After

traversing the top retorts the heating gases pass over a solid wall, known as the bridge wall, and descending, enter, by means of an opening at the bottom, a hollow chamber or upright flue, which is in communication with the main flue. The main flue is provided with suitable dampers for

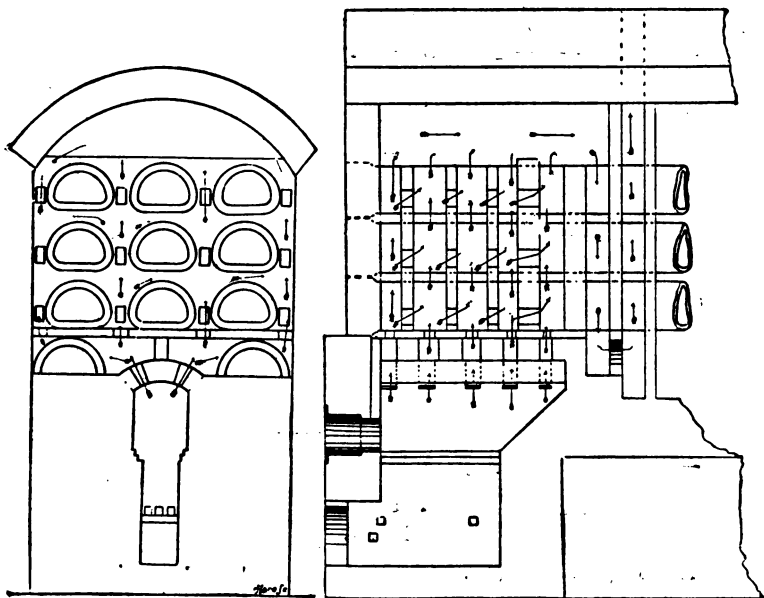


FIG. 3.

the purpose of regulating the amount of draught, which should be sufficient, and no more, to admit the necessary amount of air required for the perfect combustion of the fuel. Fig. 4 shows another method of setting retorts. Here it will be seen that the furnace is placed *between* the retorts, and the heating gases, after traversing the top retorts, descend, and then enter a flue underneath the

bottom retort; this flue is divided by a mid-feather, so that the heating gases travel first from back to front, and then back again, where it enters the upright flue in communication with the main flue, as in the first example.

Fig. 5 shows a slightly different arrangement. In this case there are four partitions, which are continued along the whole length of the retorts, so that the heating gases are blocked from passing in any direction except over the

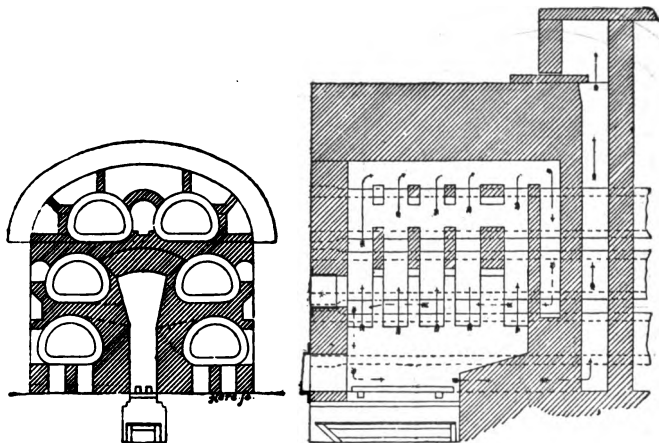


FIG. 4.

two top retorts, over which they descend, and passing to the front of the setting enter a flue beneath the bottom retorts, and from thence to the main flue. It will be noticed that in this method of setting retorts the transverse walls are dispensed with.

In retort settings of the description given, the heating gases are produced by a furnace placed at each end of a through setting. The furnace is perhaps the most important part of a setting of retorts, and it is very essential that the student should have a clear idea of what goes on

in a furnace and the "principles of combustion as applied to the heating of retort furnaces."

The fuel with which the furnace is supplied is the coke which remains in the retort after all the gas has been driven off; and coke consists principally of carbon, as it usually contains about 88 per cent. of the last-mentioned element. Now when carbon is burnt to CO_2 , a very great amount of heat is given out (1 lb. of carbon when burnt to CO_2 , yielding 14,500 heat units), and it is the resulting combustion of the coke in the furnace with the air which is drawn into the latter which gives the necessary heat to the retorts.

Furnaces are divided into three classes: the ordinary, or direct-fired, the generator, and the regenerative, or recuperative. In the ordinary open or direct-fired furnace the fuel is burnt direct to CO_2 , while in the modern generator, or regenerative furnaces, the combustion takes place in two stages, as described later on.

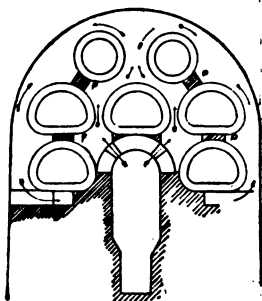


FIG. 5.

The great defect of the direct-fired furnace is the difficulty of controlling the air supply, which results in a greatly increased consumption of fuel, together with irregular heating of the setting. It is quite impossible to regulate the air supply to furnaces of this class with any degree of exactness; the speed at which the air must necessarily pass through the furnace to develop the proper amount of heat, and also the impossibility of the whole of the oxygen of the air coming into contact with the carbon to be taken up, compels the admission through the grate bars of an ordinary or direct-fired furnace, of about double the quantity of air theoretically necessary,

and consequently double the quantity of nitrogen, which has the effect of retarding the combustion and reducing the heat; on the other hand, if this excess be not admitted, then there will be a waste of fuel, caused by the combustible gas carbonic oxide, leaving the setting unconsumed, by reason of not being supplied with the oxygen in the form of air necessary for its conversion into CO_2 .

In any form of furnace the aim should be to admit sufficient air to convert the fuel into CO_2 , any excess or deficiency being detrimental to the heating of the setting.

In furnaces constructed on the "generator" principle, instead of constructing the furnace so that immediate and complete combustion of the fuel shall take place, it is so designed, that the primary supply of air entering at the bottom of the furnace, shall be sufficient only for the combustion of a portion of the fuel lying nearest to the point of ingress of the air, and that the CO_2 gas generated by the combustion of this portion of the fuel, shall, in passing through a further considerable stratum of coke, yield up a portion of its oxygen to this mass of fuel, and become thereby reduced to carbonic oxide (CO), thus, $\text{CO}_2 + \text{C} = 2 \text{CO}$. The oxygen absorbed by the stratum of fuel through which the carbonic acid gas as the product of the initial combustion passes, maintains the whole mass of fuel in a state of slow and partial combustion, and the hot gases passing away (consisting chiefly of carbonic oxide, which is a combustible gas) are capable of being rekindled and finally consumed to carbonic acid, with the evolution of a considerable amount of heat. This is effected by introducing at the proper place a separate supply of air, known as the secondary air.

This form of furnace does not require a forced draught, its needs being supplied by not much more than one half the quantity of air necessary for complete combustion, and the fact that the remainder of the air is admitted at the

point of combustion tends still further to reduce the draught. The reason for this is that the preliminary object to be attained is the production of carbonic oxide (CO) and not carbonic acid (CO_2); the former gas requiring for its production one half the quantity of oxygen to combine with an equal quantity of carbon that is required for the complete combustion of the same to CO_2 . The other half of the oxygen is not introduced until the fuel is in a gaseous form, when a much more thorough mixing of the fuel and oxygen is brought about than can be realized when the fuel exists in the solid form as coke.

The method of heating retorts just described, is known as that of gaseous firing, and the furnace in which the combustible gas is generated is known as the producer, or generator. Figures 6 and 7 show details of one form of the same, and their relative position in the setting.

Generators vary in size according to the requirements of the setting, the chief point to be attended to being to allow a good depth of fuel of comparatively even thickness (from 4 to 6 feet deep); they run from 4 to 6 feet in length, and from 2 to 3 feet in width. The arches at the top are generally formed of two rings of $4\frac{1}{2}$ -inch arch bricks, struck to the required radius, and provided at intervals with nostril holes. The sides are usually made 9 inches in thickness. The air, which is admitted to the generator is known as the primary air, and care must be taken to seal the bottom of the producer air-tight, so as to prevent any air entering except through the primary air inlet. The latter must be arranged to admit of easy adjustment, as only just sufficient air is required to produce carbonic oxide, any excess only increasing the temperature at the base of the generator, resulting in local heating.

In order to obtain good results with this class of furnace it is necessary to conduct the combustible gas (CO) under the whole length of the setting, by arranging a number of

ports from which it can issue, the secondary air being admitted alongside of it by means of corresponding ports; this obviates the intense local heating and imperfect distribution of the heat which occurs when the combustible gas issues in one or two places in a large volume.

Another and most important advantage which attends the use of this form of furnace is, that the waste heat, which in the ordinary furnace goes away to the chimney, is utilized in heating the secondary air, with the result of a considerable gain in fuel. When such heat is utilized, the furnace is said to be a regenerative, or recuperative, furnace, and when the secondary air is not heated, the furnace is termed a generator furnace.

The heating of the secondary air is effected by causing the heating gases, which have done their work in heating the retorts, in place of passing away direct to the chimney, to enter a brickwork chamber, termed a regenerator, placed on either side of the producer; the regenerator is arranged in such a manner that the spent gases pass in a downward direction, through a series of flues, to the main flue, which in this type of furnace is placed underneath the setting, while the incoming secondary air passes by a separate channel in an upward and opposite direction to meet the combustible gas. The details of the construction of regenerators vary somewhat, but the aim in every case is to cause the secondary air to take up as much heat as possible, while the waste gas loses heat in a similar proportion.

A simple form of regenerator consists in dividing the latter into two chambers, one for the waste gas, and another for the secondary air, so that the waste gas travels from back to front downwards, while the secondary air in the adjoining chamber passes from front to back upwards. Another method allows the waste gas to travel vertically downwards while the secondary air travels in a zig-zag direction upwards, and also from side to side, so as to

encircle the waste gas chamber. By this arrangement the secondary air is raised to a temperature of about 1800°F .

From fig. 6, which has some of the details omitted, the student should now be able to follow the arrangement of a regenerative setting.

As shown, on each side of the producer there is a regenerator; the secondary air enters at the bottom, and travels vertically upwards through the hot walls of the secondary air chamber, as indicated by the arrows, and becomes gradually warmer until it emerges by a nostril hole where

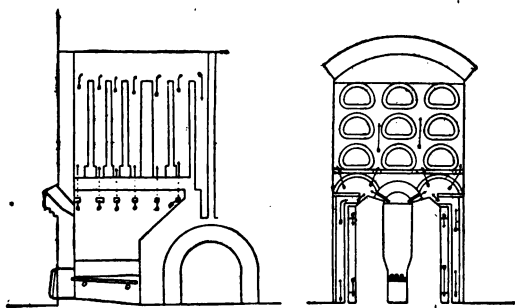


FIG. 6.

it meets the combustible gas CO , the point where combustion takes place being known as the combustion chamber. The products of combustion pass over the retorts, as shown, and then enter the waste gas chamber of the regenerator, by means of a pocket, on their way to the main flue. In travelling through the chamber the waste gases communicate their heat to the brickwork, and the secondary air in the adjoining chamber takes up heat in consequence.

Fig. 7 shows a method of regeneration more in detail.

When generator furnaces are employed, only one fur-

nace is provided for each setting of retorts, irrespective of whether they are single or throughs. The main flue is usually placed below the setting. It will be seen that in this form of furnace both the primary and secondary air are completely under control, so that by an analysis of the "producer" and "spent" gases the necessary amount of air can be easily admitted, according to requirements.

The principal advantages claimed for this system of firing are:

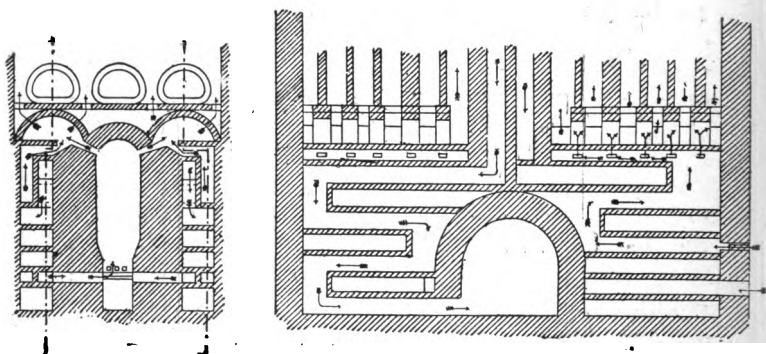


FIG. 7.

A saving of 50 per cent. in fuel over the direct-fired furnace.

Saving in labour.

Increased make of gas, owing to good and regular heats.

Saving in wear and tear of materials.

For further information concerning regenerator furnaces the student is referred to Graham's "Construction and Working of Regenerator Furnaces" (Spon and Co.).

The amount of fuel required for heating retorts is a very important item in the economy of a gas-works. In small works, where the retorts are not kept constantly at work, it may amount to as much as 35 or 40 per cent. of the coke

produced, which is reduced in large works to about 25 per cent., which has been still further reduced by the employment of regenerative furnaces to as little as 10 lb. per 100 lb. of coal carbonized.

One of the appurtenances of a furnace is the ash-pan, which is best constructed of wrought iron. Its office is to retain the ashes and small cinders which are continually dropping through the furnace bars; the ash-pan should always be kept partly filled with water, the steam from the latter fulfilling the important function of keeping the furnace bars from becoming excessively heated. The aqueous vapour passing up continually through the incandescent fuel, becomes decomposed with the production of carbonic oxide and hydrogen, which are heating gases. Further, the steam greatly facilitates the removal of the "clinker" which is formed in the furnace. Clinker, it may be explained, is produced by the combination, under the influence of heat, of the inorganic or incombustible matter of the coke (the ash of the coal, as it is generally termed). This consists principally of silica, alumina, lime, iron, etc., which fuses together to form a kind of slag. This deposit chokes up the air passages between the furnace bars, and must be periodically removed, or the necessary amount of air required could not be obtained. The clinker is removed by means of a long bar, known as the "clinkering bar," and the operation of clinkering is a very arduous operation, hence the advantage of being able to remove the clinker with as much ease as possible.

The number of beds or settings to a bench of retorts, as well as the size of the retort-house, vary with the size of the works and the make of gas. It is a general custom at the present day, in the case of large works, to build the retort-houses with a stage, that is, in such a way that there are two levels; the retorts being drawn and charged from the upper of these, while the lower level, or coke-hole,

receives the coke, which, on being withdrawn from the retorts, falls through an opening in front of the settings into the coke-hole, where it is quenched.

The coke-hole thus formed effects an economy of space, and since the introduction of regenerative furnaces such an arrangement has become a necessity. The retorts are charged in small works by means of shovels, but in large works, particularly in London and its vicinity, the instrument known as "the scoop" is invariably employed. The scoop generally holds a hundredweight of coal, and in charging by means of the same three men are required, one of whom takes the cross-handle, and the other two lift the opposite end, or "nose," by means of a bar of iron fitted to the circle of the scoop, and known as a "horse," and guide the scoop into the open retort; the scoop is then pushed in as far as possible, inverted, and quickly withdrawn, when it leaves the coal in a comparatively even layer on the bottom of the retort. This operation is repeated as often as necessary. The coal is backed off the mouthpiece by means of the "backing rake," and the mouth of the retort is then quickly closed by means of the lid described later on, the whole operation being performed in something under a minute.

A great deal depends upon the manner in which the coal is deposited in the retort, as good carbonizing results can only be obtained when the charge is placed in the retort in a thin *even* layer; for should the coal be charged irregularly, that is, in thick and heavy, and light and thin portions alternately, then the rich illuminating gases will be expelled from the thin portion before the regular time for drawing the charge, with the result that gases of little or no illuminating value, and which in some instances are actually prejudicial, will be driven off, and probably reduce the illuminating power of the gas obtained from the charge generally, while the thick portion will probably not be pro-

perly carbonized in the usual time allowed, with the result that the maximum amount of gas which is capable of being evolved from the coal will not be obtained, consequently producing a low make per ton. Further, charges of this description tend to reduce the heats of the retorts, and produce an inferior coke.

With cannel coal, or the richer descriptions of gas coals, the duration of the charge is generally either three or four hours, but with the ordinary bituminous gas coals six hours is the usual time required for carbonization. "During the first hour or so the evolution is always greatest, the gas being rich in all its constituents, but containing also a large proportion of CO_2 . Each succeeding hour the yield diminishes, accompanied by a very appreciable falling off in illuminating value, until towards the close of the charge the gas becomes scarcely worth collecting."

When the coal has given up all its gas the retorts are drawn. In drawing the retorts the lid is loosened a little, and a light applied, in order to avoid the slight explosion which would otherwise occur, to the detriment of the retort. The lid is then fully opened, and the coke withdrawn by means of long rakes. The rakes employed are generally made of three-quarter round iron, and are about 12 feet long, having a handle at one end; while the other end, with which the coke is withdrawn, is provided with a flattened head. In the drawing of through retorts the rakes employed are larger, and the drawing as well as charging takes place at each end simultaneously by separate gangs of men.

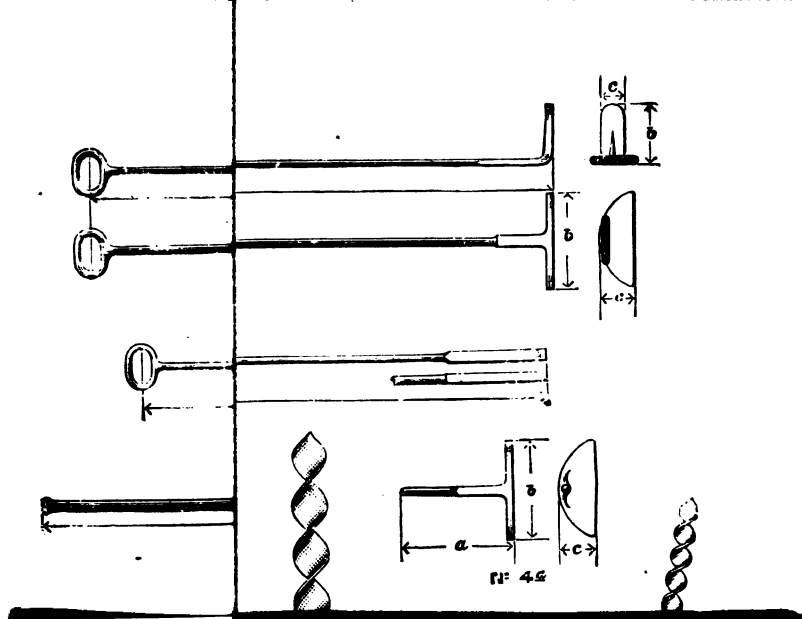
Plate No. 1 shows the tools employed in the retort-house, with their respective names, as supplied by Messrs. R. and J. Dempster, Limited, of Manchester :

Nos. 1 and 2. Stokers' drawing rakes.

No. 3. Scaling bar.

- Nos. 4 and 4a. Drawing rake ends.
- No. 5. Clinkering bar.
- Nos. 6 and 7. Augers for clearing ascension pipe.
- Nos. 8 and 9. Tongs.
- No. 10. Prickers for clearing grate bars.
- No. 11. Ash-pan shovel with welded shaft.
- No. 12. „ „ interchangeable shaft.
- Nos. 13 and 14. Hand-charging scoops.
- Nos. 15 and 16. Charging scoop carriers.
- No. 17. Stoking shovel.
- Nos. 18 and 19. Coke forks.

There is continually being deposited on the walls of the retorts a deposit of carbon, technically known as "scurf," and this deposit is much increased when the gas is subjected to an excess of pressure in the retort, as when an exhauster is not employed; so it becomes necessary to remove this deposit of carbon periodically. This is sometimes effected by chipping it off by means of chisel bars; but there is a risk of damaging the retort by so doing. A better plan is to loosen the retort lid, and thus allow the oxygen of the air to burn away the deposit until it becomes sufficiently thin to be manageable. Clay retorts require scurfing about once a month, and they should never be allowed to continue working for too long a period without being scurfed, as the deposited carbon becomes more difficult to remove the longer it is allowed to accumulate.



CHAPTER III.

THE DESCRIPTION AND ARRANGEMENT OF APPARATUS EMPLOYED FOR THE CONVEYANCE OF THE GAS IMMEDIATELY UPON ITS LEAVING THE RETORTS.

THE apparatus through which the gas is conveyed immediately upon its leaving the retorts is shown in fig. 2, and comprises the iron mouthpiece; the ascension pipe; the arch or saddle pipe; the dip pipe; the hydraulic main; and the gas main.

The mouthpiece is made of cast-iron, and is attached to the clay retort either by bolts and nuts, or by an arrangement described later on; it is provided with a door, which is sometimes made out of a wrought-iron plate cut to the shape of the retort, and provided with lugs, by which it is supported on the mouthpiece.

In order to make a gas-tight joint a luting, composed of one part of spent lime and two parts of sand or clay, is spread on the lid by means of a trowel, the door is placed in position and then tightened up by means of a cross-bar and screw fastener, but in modern establishments doors which do not require any luting, and which are known as "self-sealing," are now almost exclusively employed.

There are various descriptions of self-sealing lids, but it will be sufficient to describe the one which is most commonly employed, viz., Morton's, with Holman's eccentric fastener.

Morton's lid, fig. 8, is made of cast-iron, cast to the

shape of the mouthpiece, and is faced and planed, the mouthpiece being also faced and planed where the two surfaces are brought into contact. The lid is fixed to the mouthpiece, but is capable of swinging round by the aid of a swivel hinge. When in use it is secured by a catch on the opposite side to the swivel hinge, and is tightened up by the eccentric fastening invented by Mr. Holman.

It is found, in practice, that the best shape of mouthpiece for insuring a tight joint with this description of self-sealing lid is the round, as the pressure in this form of lid is transmitted equally on each and every portion of the

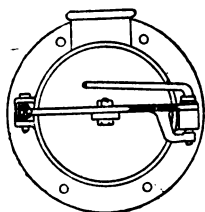


FIG. 8.

same, which is not the case with the other shapes, such as the D, on account of the unequal division above and below the cross-bar; it is consequently advisable, except where mechanical stoking is employed, to make the iron mouthpiece of the same shape as the retort, say a D, but to have the portion which comes into contact with the lid of a round section, and thus

secure a tight joint.

As previously remarked, the mouthpiece is usually attached to the retort by bolts and nuts, the bolts being inserted in the head of the retort before the latter is placed in position; but this method of attachment is not to be recommended, as the bolts are liable to be burnt away, with the consequent risk of causing the mouthpiece to come down; and even if the bolts are not burnt through, the weight of the retort mouthpiece, ascension, and saddle pipes, which are connected to the retort by the aid of the bolts, often cause the latter to break; so, in order to avoid this, numerous devices have been adopted in order to get the weight of the various fittings from the retorts themselves. One of the simplest is to brace up the mouth-

piece by T-iron girders $4 \times 4 \times \frac{1}{2}$ inches, as shown in the figure, the latter in turn being bolted to, and kept in their place, by the wrought-iron buckstays which brace together the setting. Attached to the mouthpieces are the ascension pipes; these are usually made of cast-iron, although at the present time pipes of wrought-iron and steel are being manufactured, their chief recommendation being that of lightness. Ascension pipes are usually made of a diameter of 6 inches at the mouthpiece, and taper to 5 inches at the junction with the arch or saddle pipe, the dip pipe also being 5 inches in diameter. There are various forms of the pipe known as the "arch," "bridge," or "saddle" pipe, the chief essential in designing the same being to make provision for easy access in case of stoppage, as shown in the figure.

The hydraulic main, in conjunction with the dip pipe, acts as an automatic valve, whereby the gas is allowed to go freely forward during the process of carbonizing, but is prevented from returning when the mouthpieces of the retorts are opened during the process of "drawing" and "charging."

The hydraulic main may be described as a large pipe, set perfectly level, and extending the whole length of the retort benches, and receiving the dip pipes from the different benches of retorts in its passage. It is made in various shapes—rectangular, D-shaped, or round; and is usually supported above the retort bench by means of brick piers, or cast-iron standards, placed at suitable intervals. The hydraulic main contains a mixture of tar and ammoniacal liquor which is kept at a predetermined level by an adjustable overflow.

The gas, on leaving the retort, travels by way of the ascension and arch pipes to the dip pipe, down which it passes, and bubbling through the liquid in the hydraulic main, escapes at the top of the liquid, and from thence

passes away to the condensers. The dip pipe previously referred to "dips" into the hydraulic main to a certain distance below the level of the liquid contained therein, and is then said to have a certain "dip," or "seal," the amount of the latter being usually from $1\frac{1}{2}$ to 2 inches.

Some few years ago it was suggested that it would be a decided advantage to dispense with the hydraulic seal, and for two reasons; firstly, in order to prevent the resulting pressure and oscillation which is one of the chief causes of the deposition of carbon on the interior surface of the retorts, and probably of the stoppages which occur in the ascension pipes; and secondly, in order to obviate the injurious effect due to the gas having to force its way through the tar seal in the hydraulic main, which was considered to have an injurious effect on the illuminating constituents of the gas. As a result of the investigations into the matter, numerous devices were brought forward to take the place of the hydraulic seal, such contrivances being known as anti-dips; but, after being thoroughly tested, the general conclusion arrived at was, that the employment of anti-dips was not advantageous, and that the old-fashioned dip was to be preferred, provided that the dip pipe is sealed in ammoniacal liquor, and that the tar as it accumulates is drawn off, as explained further on.

As already stated, the hydraulic main is made of various shapes in cross section, the one shown in the drawing being one of the most common.

The apparatus is now generally made of wrought-iron, on account of its lightness, and is usually constructed out of plate iron of from a quarter to five-sixteenths of an inch in thickness, and $3 \times 3 \times \frac{3}{8}$ inches angle iron. The cover, however, is usually made of cast-iron.

In modern establishments the hydraulic main is divided into separate lengths, corresponding to either one or two settings of retorts, each section being provided with its own

valve, and connected into a gas main running behind and parallel to the hydraulic main on the top of the retort bench, the pipe which conveys the gas from the hydraulic main to the gas main being provided with a weir valve, for regulating the level of the liquor in the hydraulic main as shown. In some works the hydraulic main is of such a length that it serves for six or seven settings, the gas in this case being taken off at the end of the hydraulic main. This plan dispenses with the gas main running along the back of the hydraulic main.

The hydraulic main should be of such width in proportion to the area of the dip pipes, and their distances apart, as to provide sufficient liquid for sealing them against the maximum back pressure which can reach them.

As previously remarked, the hydraulic main is usually supported by means of cast-iron standards, or brick piers, which rest upon the brickwork of the retort bench, but this method is not to be recommended, as owing to the unequal expansion of the brickwork when heated, the hydraulic main also suffers unequal expansion, with the result that it becomes out of level; and as it is absolutely necessary that the hydraulic main should remain perfectly level, this is a very serious defect, as it may cause the dip pipes to become unsealed, and thus draw in air. A better plan, and one which is now being generally adopted, is to place the hydraulic main on transverse girders, as shown in the drawing, the latter in turn being themselves held up by the buckstays which brace together the retort bench. This method possesses the further advantage that it prevents the heat of the retort bench from volatilizing the lighter portions of the tar in the hydraulic main, with its accompanying evil of the formation of pitch in the latter.

In connection with the subject of pitch in the hydraulic

main, it may be remarked that in the hydraulic main as usually met with, the liquid contents of the latter consist of a thick pitchy tar, and ammoniacal liquor. The lower portion of this tar is necessarily more or less stagnant, and is subjected at the bottom of the dip pipe to a continuous blast of gas fresh from the intensely hot sides of the retorts. The tar, therefore, is sufficiently heated to boil until every vestige of its fluidity is gone. The effect of this is, that in time the dip pipe is closed by a substance in a condition of viscousness and tenacity the very opposite of that which is required to give efficacy to its action. This throws pressure on the retort, causing loss through its pores, active deposition of carbon on its sides, and a constant choking of the ascension pipe, near the mouthpiece especially, but more or less throughout its length, occasionally even implicating the H-pipe.

What is required is to keep the tar in the hydraulic main in a fluid condition, and Mr. G. Livesey achieves this, by diminishing the bulk of the stagnant tar in the hydraulic main by placing in the latter only sufficient (say from four to six inches) to seal the dip to the required depth; consequently, as this quantity bears only a small proportion to the yield of tar from the gas, it is constantly being pushed forward to the overflow and renewed.

When a hydraulic main is first put to work, it is filled either with water or ammoniacal liquor, but in the ordinary way of working this is soon replaced by tar, generally of a high specific gravity, which, as previously shown, is injurious on two grounds: first, by reason of the tar abstracting a portion of the illuminating constituents of the gas; and, secondly, by causing a heavier seal, which is one of the causes of stopped ascension pipes. It is consequently desirable to provide means for the removal of the heavy tars from the hydraulic main as soon as they are deposited, and thus insure the dip pipes being sealed in liquor.

A method of doing this is shown in fig. 9, as devised by Messrs. R. and J. Dempster, of Manchester. This method possesses the further advantage that it enables the gas to travel to a great extent out of contact with the tar, for it has been observed that if the tar be allowed to travel forward with and cool with the gas, that the latter will suffer a loss of illuminating power by reason of the lighter hydrocarbons being absorbed by the heavier hydrocarbons

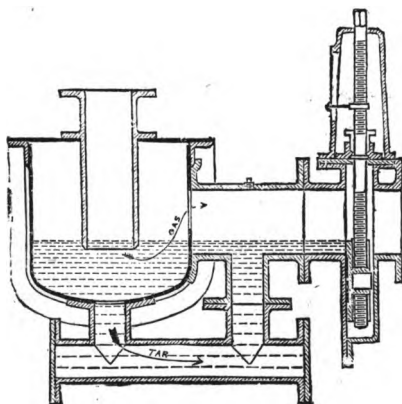
**NEL**

FIG. 9.

contained in the tar; the converse result being the case to some extent if the gas is kept in contact with the tar at a sufficiently high temperature.

With regard to the stoppages in ascension pipes, it is considered that the cause of such stoppages is due to high heats, and to the pressure caused by the hydraulic seal. The remedy is to keep the pipes cool, and to have as light a seal as possible, and the dip pipe to "dip" in liquor only. The ascension pipes may be kept cool by making the front walls of the settings a brick and a half thick,

so as to prevent undue radiation from the latter, and to arrange the pipes so that they project about eight inches from the front of the setting. Another very good plan is to allow a gentle stream of water to drip into a funnel fitted to the top of a goose-neck syphon, attached to that portion of the H-pipe which is connected to the ascension pipe, and a further preventive, and one which should never be omitted, is to use the bent auger, shown on Plate No. 1, before every draw.

CHAPTER IV.

LABOUR-**SAVING** APPLIANCES IN THE RETORT-HOUSE, AND IN THE WORKING OF RETORTS.

THERE have been numerous attempts made to solve the problem of doing away with, or mitigating, the arduous labour of the retort-house, and thanks to the efforts of Mr. John West, of West's Gas Improvement Company, Limited, and others, such attempts have been perfectly successful. Mr. West was one of the first to grapple with the question, and, by patient application, he ultimately surmounted the numerous difficulties which had to be overcome. Mr. Foulis, of Glasgow, was also early in the field, working at the same project, but on different lines, and at the present time the stoking machines of Messrs. West, and of Messrs. Foulis and Arrol, are those generally found in English gas-works. One of the greatest difficulties with early stoking machinery was the question of preparing the coal and conveying it to the charging machine, and it was not until Mr. West had invented and carried out the system of mechanically conveying the coal to machines that any definitely good results were obtained.

When constructing the Manual Charging and Drawing Machines, Mr. West did not attempt to dispense with manual labour to its fullest extent, but to relieve the men of the exposure to heat, and to facilitate the operation of charging and drawing retorts, so that a minimum amount

of gas should be lost while the retort was open during the process of charging.

The result has been that, in addition to these advantages, a considerable saving has been effected on the cost per ton of coal carbonized.

The manual type of Charging and Drawing Machines meets the requirements of small and moderate-sized works, and is successfully employed in gas-works having an annual make of twenty millions, and in works of a much larger make.

The following is a description of West's "Manual" Stoking Machinery, and its appurtenances, comprising coal breakers, coal elevators and conveyers, and coal-hoppers.

The coal breakers are fixed in the coal stores in pits covered by iron framing and floor plates.

The breaker is generally driven by a steam-engine combined with it, or a separate gas-engine can be used for driving the breaker in places where steam is not available. After the coal is broken, it is elevated to hoppers fixed overhead in the retort-house, on girders spanning between the coal store and the retort stack. The elevators consist of malleable iron buckets fitted to a strong detachable link chain. The elevators are driven by belting and chain gear from the coal breaker engines.

In cases where the coal stores are only on one side of a retort-house, containing "through" benches of retorts, the coal is conveyed to the hoppers by horizontal conveyers fixed over the retort bench. The overhead coal-hoppers are fixed conveniently in the retort-house and provided with sliding outlet doors, and levers for supplying coal to the charging machines as they pass under.

The "manual" type of charging machine consists of a square upright frame on wheels, which run on tram rails laid in front of, and parallel to, the retort stack.

The machine is propelled by a hand-wheel and gear fitted to one side of the machine, and on the opposite side, there is a hand-wheel and gear for hoisting and lowering an adjustable coal-hopper from one tier of retorts to another.

The adjustable coal-hopper on the charging machine receives a supply of coal for a number of retorts from the overhead fixed coal-hoppers in the retort-house, and is free to move up or down between the four uprights of the charging machine frame, being guided by them, and suspended by chains leading over pulleys carried by the top cross members of the frame. A light frame is suspended from the coal-hopper for carrying the charger when it is out of the retort. At the bottom of the hopper, but directly over the charger, is a feeder-box, controlled by a hand-wheel when supplying the charger with coal.

The "West" manual charger consists of a light carriage, running on three wheels and having two semicircular scoops at the bottom. These scoops are arranged to turn over in opposite directions by the twisting of the long driving-rod about half way round in one direction, and, when turned over, all the coal contained in the charger is free to fall out on to the floor of the retort.

The method of working the charging machine is very simple, and is as follows :

The machine receives a supply of coal from the overhead hopper, and is propelled to the retort which is to be charged. Arriving opposite the retort, a drawbridge, hinged to the frame carrying the charger, is allowed to fall until it rests on the front of the floor of the mouthpiece. The stoker then gives the hand-wheel controlling the feeder-box a few turns, whereby the coal is allowed to flow from the hopper until the charger is full. The charger is then pushed into the retort by means of the long rod, and on arrival at the end of a single retort, or just past the middle of a

"through," the handle and rod are turned so as to reverse the scoops forming the bottom of the charger, and the coal falls out. The charger is drawn back into the machine, is filled as before, then it is pushed into the same retort to a previously arranged distance, the scoops turned over, and the charger withdrawn. The retort will then be charged with an even layer of coal, slightly deeper at the sides, and so perfect, that no skilled stoker can equal it either by the use of the scoop or shovel.

After charging a retort, the machine is propelled to the next retort in the same tier, and so on, until the stipulated number of retorts are charged.

The manual type of drawing machines is a frame on three wheels, carrying an adjustable arm, supporting the rake rod with its head. Hoisting gear is fixed to the frame, to adjust the rake rod and head to the several tiers of retorts. The machine is constructed so as to enable a coke barrow to be placed under the mouthpiece, and the coke can then be drawn direct into the barrow.

A removable platform is used for drawing the top tier of retorts. By means of this machine the stoker is enabled to use a large, wide rake head, as the effort to lift its weight is taken by the machine.

For large works Mr. West employs power-driven stoking machinery, the power being either compressed air or machine-driven cotton or wire ropes.

In the "West" charging machine the action of the scoop in charging by hand is reproduced.

The scoop, which is the full length of the retort, enters twice, emptying itself alternately left and right. It is constructed with a thin blade running down its centre, the object of this being to throw over and distribute the coal evenly on the floor of the retort when the scoop is turned. The scoop holds two hundredweight of coal. The carrier to which the scoop is attached runs in horizontal guides on

the framing of the machine. Each extremity of this carrier has a chain affixed thereto which is wound round a drum. By means of a rack and pinion this drum is rotated in either

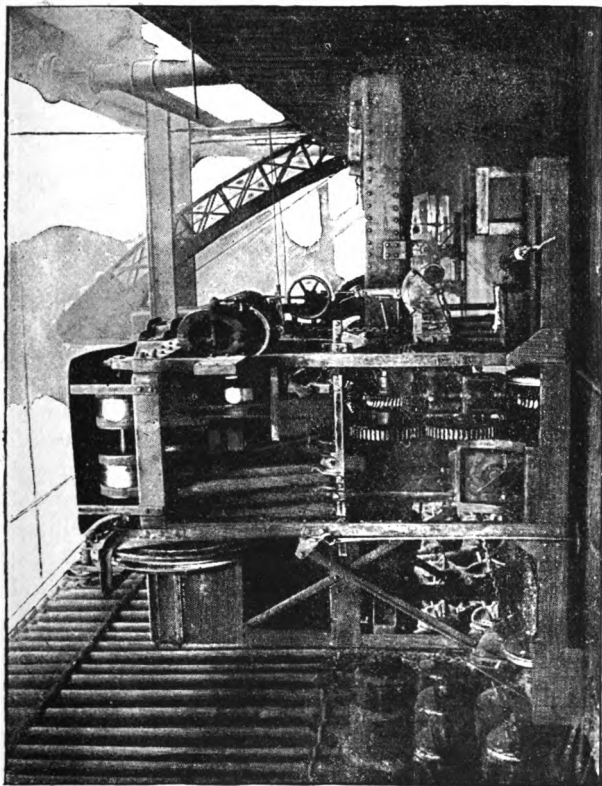


FIG. 10.

direction as required, and the carriage with the scoop thus drawn in and out of the retort as required, the necessary power for working the same being supplied either by compressed air, or cotton or wire ropes.

Fig. 10 shows West's Charging Machine driven by a cotton rope.

In the Foulis-Arrol system of stoking, the motive power is supplied by hydraulic pressure.

In the drawing machine, the rake is composed of a steel bar of H section, on the under side of which works a slide, to which is attached a steel rake rod.

On the upper side of the bar are fixed two hydraulic rams, one for the purpose of propelling the rake into the retort, the other for withdrawing it. A 1-inch circumference steel wire rope passes from a fixed point round a sheave on the end of each ram on to the slide, to give the required motion; the stroke of the rake being double that of the ram. The rake is suspended about the middle of its length by a steel wire rope connected with a vertical ram, by means of which it is raised and lowered to suit the heights of the several tiers of retorts.

The working of one lever performs the four successive operations of raising, propelling, lowering, and withdrawing the rake, and a second lever in connection with the vertical ram raises and lowers the rake bar. The whole is fixed within a light L-iron framework carried upon travelling-wheels running on rails laid to a gauge of 7 feet 7 inches, and is easily propelled by one man by means of bevel gearing.

The water from the cylinders is conveyed, after being used, into a tank fixed at the top of the framing, from which the quantity required for cooling the rake head is drawn. The quantity can be regulated by the man in charge of the machine, the excess overflowing by a separate pipe.

The charging machine, fig. 11, somewhat resembles the drawing machine in its appearance and general construction, the main points of difference being the addition of a hopper for carrying, and the arrangements for delivering the coal.

The hopper is a fixture in the front, and on top of the machine, and will hold sufficient coal for charging twenty

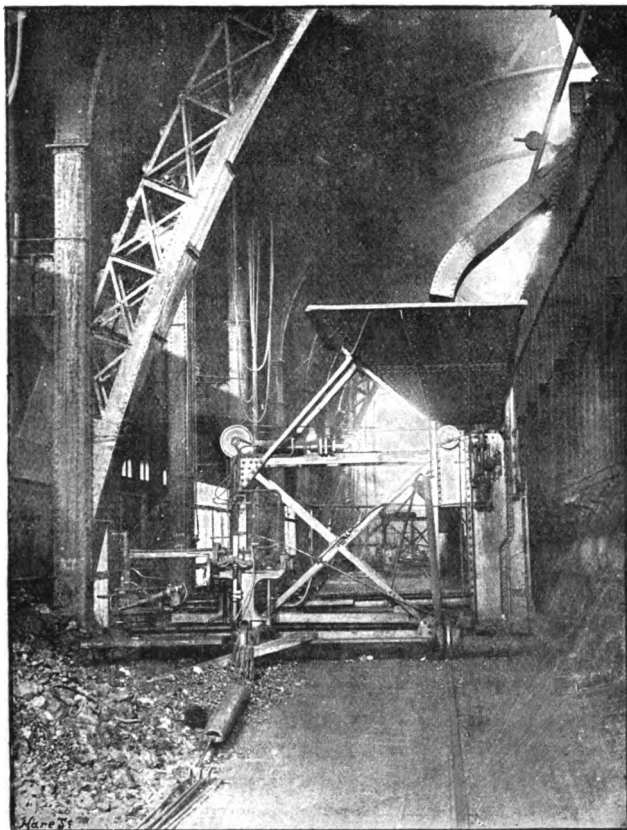


FIG. 11.

retorts. This hopper is filled as required by a stationary overhead hopper, fixed above the retort settings, and supplied with coal by an elevator, the coal previously passing

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through a breaker. The coal is delivered into the retorts by a series of "pushes," effected by means of a rod with a plate at the end, connected to two hydraulic rams, as in the case of the rake, worked in precisely the same manner as the rake, the only difference being that the push-plate is of a different shape, and rather larger than the rake head. The charge of coal is delivered in front of this plate by means of a revolving drum fixed immediately under the hopper, and divided by radial partitions into a number of chambers. This drum has a continuous rotary motion imparted to it by the action of two small hydraulic rams, by means of a ratchet and pawl arrangement, the extent of the revolution of the drum determining the amount of coal discharged therefrom. This can be easily regulated to the amount required for the charge.

The connection between the machines and the mouthpiece of the retort is effected by a sliding plate, with shallow sides to it, controlled by the driver from the platform on which he stands, the plate being so constructed as to enter the mouthpiece about two inches. This plate receives the coal as it falls from the drum. It will be evident that, in charging a retort, each stroke of the pusher must be shorter than the preceding one, and, in order to automatically effect this shortening of the stroke, there is provided a revolving shaft, placed parallel with the charging ram, having fixed upon it, at equal distances, six stops or projections placed radially out of line.

The shaft being given a sixth of a turn by a ratchet and pawl arrangement, actuated by the lever which works the pusher, brings the stops successively in the path of the ram and shortens the stroke each time $16\frac{1}{2}$ inches until the seventh stroke, when the charge is complete. If it be desirable to miss the last stroke by reason of the mouthpiece of any retort being dull, the driver can operate the revolving shaft by means of a hand-wheel attached

thereto, and bring it into position for making the first or long stroke for the next retort.

The pusher with all its attachments, including a platform for the driver, is suspended, raised, and lowered in the same manner as the rake bar previously described. As in the rake, the movement of one lever, communicating with the valves, suffices for all the operations of charging the retort, with the exception of the adjustment of the sliding plate into the mouthpiece, which is worked independently by hand.

The hydraulic power is supplied by a duplex high-pressure pumping engine, driving direct four single-acting plunger-pumps, working into an accumulator weighted to give a pressure of 400 lb. to the square inch.

The foregoing particulars have been obtained from a paper read by Mr. Joseph Tysoe before the Incorporated Institution of Gas Engineers in 1894.

CHAPTER V.

THE EFFECTS OF TEMPERATURE IN MODIFYING THE QUANTITY AND QUALITY OF THE GAS PRODUCED.

WHEN coal is subjected to the action of heat in a closed vessel it undergoes the process of destructive distillation, yielding various products, which may be broadly divided into solids (coke and retort carbon), liquids (tar and ammoniacal liquor), and gases consisting of the unpurified or crude coal-gas; and it is the effect of heat on the latter product which forms the subject of the present heading.

The quality and illuminating value of the gas produced from any sample of coal varies greatly with the condition of the coal at the time of distillation; whether it be old or fresh wrought, whether wet or dry. The temperature at which the distillation is conducted is, however, the most important factor in the ultimate results obtained. As would be naturally inferred from a study of the elementary composition of coal, the chief products of the distillation are compounds of carbon and hydrogen, the greatest portion of the carbon in the original coal being left behind in the retort in the form of coke. These compounds of carbon and hydrogen are produced in three different forms, viz., gaseous, liquid, and solid, as previously pointed out.

It is one of the canons of organic chemistry that the higher the temperature and the more advanced the decomposition of a substance, the simpler are the products thus produced; and so, when an organic substance such as

bituminous coal is distilled at a comparatively low temperature, the carbon passes off with but little hydrogen, liquid compounds of carbon and hydrogen are formed, consequently we get *plenty of tar and little gas*, the latter, however, being of a *high illuminating power*; but if we gradually increase the temperature, the liquid hydrocarbons decrease, while the gaseous products increase, that is, we find *more gas and less tar*; increasing the heat still more, we find that the gaseous products are richer in hydrogen and poorer in carbon, marsh-gas, or methane, is formed in great abundance, and finally, when the temperature becomes still higher, free hydrogen is given off, this result always occurring towards the end of the operation of gas-making.

With an increase of temperature the strength of the union between carbon and hydrogen appears to decrease. Ethylene passed over a highly heated surface deposits a portion of its carbon in the solid form, and is converted into methane and hydrogen.

Now when coal is destructively distilled in retorts heated to a proper temperature, it is exposed to two different conditions.

In the first place, the exterior surface of the coal coming into direct contact with the hot walls of the retort is immediately decomposed, such hydrocarbons as ethylene are produced, which at this temperature are partly decomposed and converted into methane and free hydrogen, with an accompanying deposition of carbon, these gaseous products, together with some undecomposed ethylene and volatile hydrocarbons, passing off from the retort.

The interior of the mass of coal is subjected to a somewhat different treatment, as for some time it is exposed to only a very moderate heat, which effects a simple distillation, with the result that those compounds that are formed at a comparatively low temperature, the heavy hydro-

carbons, which would ordinarily be in a liquid state, are eliminated, a portion, rising into vapour as it reaches the hotter surface, passes off with the gases formed, and is again condensed on leaving the retort in the form of tar; but that portion of the vapour which in its passage comes into contact with the red-hot surface of the exterior mass of coal, and of the sides of the retort, deposits a portion of its carbon, and is decomposed into simple compounds, ethylene and volatile hydrocarbons, which in turn are also partly decomposed. As the heat penetrates to the centre, and a red-hot mass of charred material of considerable thickness consequently surrounds the decomposing coal in the interior, which is the case towards the end of the distillation, the whole of the hydrocarbons which are then given off are decomposed by having to pass over such an extent of heated surface, and free hydrogen is almost alone given off.

Further,¹ "there is no doubt that paraffin hydrocarbons are present in the original coal. These paraffins, under the influence of heat, split up into simpler members of the same series, and into olefines; and if we imagine the action in its simplest form, we should have the gases as they were evolved consisting of (say) ethane and ethylene. These have now to pass down the heated retort on their way to the ascension pipe, and the contact with the heated sides of the retort, and the baking from the radiant heat in the retort, set up an infinity of changes.

"Ethane when heated to this degree splits up into ethylene and hydrogen, while ethylene decomposes to methane and acetylene, and the acetylene at once polymerizes to benzene, styrolene, retene, etc. A portion also condenses, and, at the same time losing some hydrogen, becomes naphthalene; and the compounds so formed by

¹ Professor Lewes, "Journal of Gas Lighting," vol. lxiii., p. 282.

interactions among themselves build up the remainder of the hydrocarbons present in the coal-tar, while the organic substances containing oxygen in the coal break down, and cause the formation of the phenols in the tar.

“There is very little doubt that the general course of the decompositions follow these lines; but any such simple explanation of the actions taking place is rendered impossible by the fact that, instead of the breaking down of the hydrocarbons being completed in the coal, and only secondary reactions taking place in the retort, in practice the hydrocarbons to a great extent leave the coal as the vapours of condensable hydrocarbons, and that the breaking down of these to such simple gaseous compounds as ethylene is proceeding in the retort at the same time as the breaking up of the ethylene already formed into acetylene and methane, and the polymerization of the former into higher compounds. Starting with a solid hydrocarbon of definite composition, it would be theoretically possible to entirely decompose it into carbon, ethylene, methane, and hydrogen, and, by rapidly removing these from the heating zone before any secondary actions took place, prevent formation of tar. But any such ideal is hopeless in practice, as the coal is not a definite compound, and it is impossible to subject it to a fixed temperature.

“If the retorts are at a temperature of 1000°C . (1832°F .) when the charge of coal is put in, the temperature of the distillation will vary from about 800°C . (1472°F .) close to the walls to about 400°C . (752°F .) in the centre of the coal; and in the same way, in the space above the coal, the products which come in contact with the sides of the retort are heated to 1000°C (1832°F .), while the gas near the coal is probably only heated to 600°C . (1112°F .). Hence we find that the tar is formed of two distinct sets of products—the first due to incomplete decomposition, and the second to secondary reactions due to the products of

the decomposition being kept too long in the zone of heat.

“Of the first class the light paraffin oils and pitch may be taken as examples; while benzene, naphthalene, and retort carbon represent the second. The formation of the second class of bodies is a great loss to the gas manufacturer, as, with the exception of the trace of benzene carried by the gas as vapour, these products are not only useless in the gas, but one of them—naphthalene—is a serious trouble, as any trace carried forward by the gas condenses with sudden changes of temperature, and causes obstructions in the service pipes; while their presence in the tar means the loss of a very large proportion of the illuminating constituents of the gas. Moreover, these secondary products cannot be successfully reduced, by further heating, to simpler hydrocarbons of any high illuminating value; while such bodies as naphthalene and anthracene have so great a stability that, when once formed, they resist any efforts to again decompose them by heat, short of the temperature which breaks them up into methane, carbon, and hydrogen.”

The effect produced by changes of temperature on the quantity and quality of the gas produced from coal has been very carefully studied by Mr. L. T. Wright, who found that as the temperature is raised, the yield of gas from a given weight of coal increases; but with the increase of volume there is a marked decrease in the quality of the gas obtained. Mr. Wright,¹ in a series of experiments conducted by him, found that when four portions of the same coal were distilled at temperatures which varied from a dull red heat to the highest temperature attainable in an iron retort, he obtained the following results as to make of gas and of illuminating power:

¹ “Journal Chem. Soc.,” vol. xlv., 1884, p. 99.

Temperature.	Cubic feet of gas per ton.	Illuminating power (candles).	Total candles per ton.
(1) Dull red . . .	8,250	20·5	33,950
(2) Hotter . . .	9,693	17·8	34,510
(3) „ . . .	10,821	16·7	36,140
(4) Bright orange .	12,006	15·6	37,460

The composition of the gases, generated as above, were as shown below, with the exception of No. 3, which was unfortunately lost, but its illuminating power would tend to show that its composition was intermediate between Nos. 2 and 4.

Composition of the Gas.

	(1) Per cent.	(2) Per cent.	(4) Per cent.
Hydrogen	38·09	43·77	48·02
Methane	42·72	34·50	30·70
Olefines	7·55	5·83	4·51
Carbon monoxide .	8·72	12·50	13·96
Nitrogen	2·92	3·40	2·81
	100·00	100·00	100·00

From a study of the figures in the above tables it will be seen that with the increase of temperature the saturated and unsaturated hydrocarbons, that is, the olefines and marsh-gas series, gradually are broken up, depositing carbon and liberating hydrogen, the percentage of which steadily increases with the rise of temperature, as pre-

viously described. The remarks of Mr. Charles Hunt,¹ the late examiner in gas manufacture, on this subject, will be of interest :

“There is good ground for the opinion that the best all-round results are obtained from small charges with moderate, as distinguished from very high, temperatures. It has generally been assumed that the deficient yield of tar, which usually accompanies the use of a high carbonizing temperature, is fully compensated by increased production of gas. In the author’s experience, however, the highest production of gas has been accompanied by the largest yield of tar and ammoniacal liquor.”

Mr. Hunt then proceeds to quote Mr. Wright’s experiments showing the gain resulting from the employment of the higher temperature in the table on p. 57, remarking that the results obtained in the laboratory of the Windsor Street Gas Works, Birmingham, *with very high yields* of gas, showed a falling off in illuminating value. The experiments were made on 56 lbs. of North Staffordshire gas nuts carbonized in a small iron retort, at temperatures ranging from 1400° F. to 1835° F. It was found that the best results, that is, the greatest number of “candles per ton,” were obtained at a temperature of 1600° F.

Mr. Hunt, commenting on the results of these experiments, then states that he “does not wish it to be supposed that he considers the best the temperature which gives the best result in a small iron retort suitable for the retort-house, where the coal is to be burnt off in a fixed time, viz., four to six hours, but he is of opinion that the lowest temperature which will suffice for this is to be preferred. For while the best all-round results are to be obtained by carbonizing at a fairly high temperature, it is

¹ “Minutes of Proceedings, Institution of Civil Engineers,” vol. cxvii., Part III.

essential that the gaseous products should be enabled to pass fully away without encountering in the ascension pipe any absorbent of hydrocarbons, such as thick tar. When obstruction occurs to any extent in the shape of stopped pipes, and with high temperature these are seldom entirely absent, the loss thus occasioned is likely to turn the scale in favour of a lower temperature."

The best temperature for obtaining a good yield of gas of fair illuminating power, from Newcastle coal, is that of a dull orange, which is supposed to be about 2010° F. Different kinds of coal, whether cannel or caking, give off their gas in different times, even when subjected to the same conditions as regards temperature and size of retort. Cannel, as a rule, is more easily distilled than caking coal, as it yields the whole of its gas in about one-sixth less time.

In the case of cannel coal the first hour of the charge produces the most gas, while in the case of caking coal, the second hour is usually the most productive, the difference in the behaviour of the two kinds of coal in this respect being usually set down to the fact, that in the case of caking coal the amount of moisture present is converted into steam during the first hour, and this abstracts a large portion of the heat.

CHAPTER VI.

THE EFFECTS OF TEMPERATURE UPON THE PRODUCTION OF RESIDUALS.

THE yield and quality of the products obtained in the destructive distillation of coal will greatly vary, according to the temperature of the retorts; with the amount of coal carbonized; with the manner in which it is deposited in the retorts; with the period of distillation; and with a number of other factors.

We will first discuss the effects of temperature on the residual "tar."

The quantity, and more especially the quality, of the tar greatly depends upon the temperature at which the coal is distilled. Low temperatures with 9,000 cubic feet of gas per ton of coal will yield with some coals 16 gallons of tar, whilst high temperatures will yield but 9 gallons, with about 11,000 cubic feet of gas from the same coal.¹

"If² the temperature be a comparatively low one mostly such hydrocarbons are formed as belong to the paraffin (methane) series, having the general formula $C_n H_{2n+2}$ along with olefines, $C_n H_{2n}$.

"The lower members of these series are liquid, the higher ones are solid.

"They are always accompanied by oxygenized derivatives

¹ Davis, "Journ. Soc. Chem. Ind.," 1886, p. 5.

² Lunge, "Coal-tar and Ammonia," p. 17.

of the benzene series (phenols), but of these the more complicated ones predominate.

"Liquid products prevail, and among the watery ones acetic acid (which is again a compound of the fatty series) is paramount. Of course also permanent gases are always given off, though in comparatively small quantity.

"If, on the other hand, the coal has been decomposed at a comparatively high temperature, the molecules are grouped quite differently. Whilst the olefines and members of the acetylene series still occur more or less, the hydrocarbons of the paraffin series disappear almost entirely, and from them are formed, on the one hand, compounds much richer in carbon, on the other hand, more hydrogenized bodies. The latter always occur in the gaseous state; hence the gas so produced contains methane, or marsh-gas, CH_4 , and free hydrogen, as principal constituents, and is very much increased in quantity. The carbon thus set free is partly deposited in the retorts themselves, and then occurs in a very compact graphitoidal form; another portion of the free carbon occurs in a state of extremely fine division in the tar, and forms a constituent of the pitch or coke remaining behind from tar distilling; another portion contributes to the formation of compounds richer in carbon, belonging to the aromatic series, all of which are derived from benzene, $\text{C}_6 \text{H}_6$.

"At the same time the action of heat effects further molecular 'condensations,' usually with separation of hydrogen, by which process compounds of a higher molecular weight are formed, as naphthalene, anthracene, phenanthrene, chrysene, etc. The never-absent oxygen must also in this case cause the formation of phenols, but here phenol proper, or carboic acid, $\text{C}_6 \text{H}_5 (\text{OH})$, predominates, whilst cresol and the other homologues are diminished in quantity, and the bioxy-benzenes, as well as their methylated derivatives disappear altogether."

Shortly expressed, at low temperatures we obtain less permanent gases and more methylated derivatives (toluene, xylene, higher phenols); at a higher temperature more permanent gases, together with benzene, naphthalene, and anthracene, and considerably more free carbon is formed.

We are indebted to Mr. L. T. Wright, F.C.S., for some valuable information on the effect of temperature in modifying the quantity and quality of the tar produced in the destructive distillation of coal.

Mr. Wright found that the tar produced is affected to an even greater extent than the gas by alteration in the temperature at which the destructive distillation of the coal is conducted. Mr. Wright found that an increase of temperature in the process of distillation not only augmented the volume of gas given off, but it *lowered* the weight of tar, though it doubled the amount of free carbon in the tar, the specific gravity of the latter being increased. At lower temperatures the specific gravity of the tar produced is also lower. Experimenting with a caking coal, Mr. Wright obtained the following results:

Yield of gas per ton. Cubic feet.	Specific gravity of tar.
6,600	1·086
7,200	1·120
8,900	1·140
10,162	1·154
11,700	1·206

An analysis of the tar showed that the increase of the specific gravity was due to the increase in the quantity of pitch, which rose from 28·89 to 64·08 per cent., while the NH_3 , naphtha and light oils, steadily fell in quantity, the creosote and anthracene oils following in the same direction, but to a smaller extent. It is generally known that although the actual specific gravity of the tar obtained is

greater as the temperature of distillation rises, yet the total production of tar is less. Mr. Wright's analysis,¹ showing the constituents of the various tars in the experiment just alluded to, is very instructive in this connection, for it shows that although the percentage of free carbon is augmented by increasing the temperature of distillation, a sufficient quantity of the lighter constituents of the tar is also decomposed into gas, to enable the increased proportion of carbon to be accounted for without falling back on the assumption that it is produced by the decomposition of illuminating hydrocarbons in the gas. With a make of about 7,000 cubic feet per ton, the tar contains some 9 per cent. of light naphtha, and a rather less proportion of light oil. When the make increases to about 10,000 cubic feet, the amount of these constituents falls to about one-third, or 3 per cent. of each respectively. At the highest temperature employed in Mr. Wright's experiments, not only is the quantity of light oil and naphtha reduced below 1 per cent., but a large proportion of creosote oil is also decomposed. When the decrease in the total yield of tar is taken into consideration, it is evident that the gain in pitch is more than counterbalanced by loss of light oil, naphtha, and creosote.

Differences in the quality of the coal employed also influences the quantity and quality of the constituents found in the resulting tar. Newcastle coals produce tars rich in naphthalene and anthracene; Wigan coals yield tars containing much benzol and phenol. From the experiments of Bunte,² it would appear that the quantity of tar increases with the percentage of oxygen in the coal.

Tar derived from ordinary bituminous coal varies in specific gravity from 1·1, to 1·2, and the total yield of tar from coal may be said to be, on an average, 5 per cent. of

¹ "Journ. Soc. Chem. Industry."

² "Journal für Gasbeleuchtung," 1886.

the weight, the quantity produced per ton of Newcastle coals, at ordinary working temperatures, being about ten gallons, which is increased at low temperatures, as previously explained.

The composition of tar necessarily varies. The following is taken from Professor Wanklyn's "Gas Engineer's Chemical Manual."

Ammoniacal liquor	4.0
First light oils	1.5
Second light oils	1.5
Creosote oils	22.0
Anthracene oils	4.0
Pitch	67.0
	100.00

The ultimate composition of a London tar (Professor Lewes) is approximately as follows:

	Per cent.
Carbon	77.53
Hydrogen	6.33
Nitrogen	1.03
Sulphur	0.61
Oxygen	14.50
	100.00

With respect to the effects of temperature on the production of ammonia, Mr. Wright is in this case also the leading authority.

The following extracts give Mr. Wright's view on the subject (see "Journal Soc. Chem. Industry," vol. vii., p. 59):

"The results obtained from individual experiments, lasting twenty-four hours, have never been very determinate, and it appears that there is some cause, other than the temperature

of retorts, at present unknown, operating as a disturbing element.

"The averages of large numbers of experiments however always bring out the fact that at very low distillation temperatures the yield of ammonia is low, that a medium temperature brings out a maximum, and that beyond this, higher temperatures result in a slightly diminished production.

"The following case, where the coal (whose analysis has already been given) was employed, is typical of a great many that have been obtained, and will serve as well as a larger number to illustrate the tendency."

Make per ton (cubic feet).	Yield of NH_3 per ton.	Percentage by weight of coal as NH_3 .
	lb.	
11,620	7.411	0.331
10,162	7.894	0.352
9,431	7.504	0.335
7,512	6.391	0.285

In this case the maximum yield of ammonia is with the make of 10,162 cubic feet per ton.

Mr. Wright further found that higher heats produced more bisulphide of carbon and sulphuretted hydrogen, but the product which was most remarkable with high heats was cyanogen, which was ten times as great with high heats as with low ones.

With regard to the production of coke, a high temperature generally produces a harder coke, but there are great differences in the character of the coke produced from the same coal, partly dependent on the temperature employed, and partly on the description of retort used.

Gas coke, although often spoken of as carbon, also contains nitrogen, sulphur, hydrogen, and oxygen.

Speaking generally, the products of distillation vary with the origin of the coal, Newcastle coals yielding a different class of tar to Derbyshire and South Yorkshire.

At the temperature usually employed in carbonization, the following are the products obtainable from a ton of Newcastle coal, as given by Professor Wanklyn in his admirable "Gas Engineer's Chemical Manual."

	Lb.	Per cent.
Gas (10,000 cubic feet)	380	17·0
Tar (10 gallons)	115	5·1
Virgin ammoniacal liquor	177	7·9
Coke (absolute)	1,568	70·0

CHAPTER VII.

PURIFICATION.

(Condensation.)

THE crude gas as it leaves the retorts may be said to enter the purification stage directly it reaches the hydraulic main, at which point the impurities consist of tarry bodies (impure hydrocarbons), carbonic acid, sulphuretted hydrogen, ammonia, cyanogen compounds, and sulphur compounds, other than sulphuretted hydrogen.

According to Professor Wanklyn,¹ gas, as it leaves the retorts, "is accompanied by rather less than one-third of its weight of tar, by nearly half its weight of watery vapour, by about $\frac{1}{30}$ th of its weight of ammonia, by a little more than $\frac{1}{20}$ th of its weight of carbonic acid, by from $\frac{1}{30}$ th to $\frac{1}{20}$ th of its weight of sulphuretted hydrogen, and by from $\frac{1}{30}$ th to $\frac{1}{20}$ th of its weight of sulphur in the condition of sulphuret of carbon and organo-sulphur compounds."

The first operation to which the gas is subjected is that of cooling, and as it cools, the vapours of various hydrocarbons and aqueous vapour, condense into the liquid form. The liquefied hydrocarbon vapours constitute what is known as tar, while the condensed aqueous vapour takes up ammonia, as well as CO_2 , SH_2 , and cyanogen, forming what is known as ammoniacal liquor. This cooling process commences immediately the gas reaches the retort mouthpiece, so that by the time it has arrived at the outlet

¹ "The Gas Engineer's Chemical Manual."

of the hydraulic main it will have deposited from one-half to one-third of its condensable constituents.

The temperature within the retorts may be taken at from 1800° to 2000° F., and yet in the hydraulic main the temperature will be found to be only 140° to 180° F. The reason of this difference, is due to the rapid absorption of heat by the volatile constituents of the coal in assuming the gaseous form; this heat becoming latent in the gas, in the same way as the latent heat of steam when water boils. On leaving the hydraulic main the gas has a temperature of from 110° to 150° F., and this has to be reduced to a temperature of from 50° to 60° F., and the remainder of the tar got rid of, before the gas is allowed to enter the purifying plant. These operations are performed in the apparatus known as the condensers, the operation itself being known as "condensation." The object of condensation is to take out on the works, and at an early stage, substances which cannot be retained in the gas, and which would be deposited in the purifying apparatus and distributing mains, care being taken to retain in the gas all substances which are useful in contributing to the illuminating power of the same. Water, and most of the compounds which the water holds in solution, are useless, and cannot be distributed with the gas; it is necessary therefore that these should be removed.

The heaviest hydrocarbons (tar) are useful as illuminants, but cannot be distributed with the gas as they become liquefied at ordinary temperatures; these should also be removed. The permanent gases and the lighter hydrocarbon vapours are however extremely useful as illuminating agents, and can be carried by the gas; it is essential therefore that no more of these substances be removed than is absolutely necessary to effect a proper removal of the compounds which must be got rid of on account of their uselessness as light givers, or incapability of being distri-

buted. The most useful of all substances as light givers when burnt are the vapours of hydrocarbons, and therefore great pains should be taken to keep in the gas the largest possible quantity of these vapours; the method for effecting this is described a little later on.

The operation of condensation is in reality two-fold: consisting, firstly, in cooling the gas to the required temperature; and, secondly, in removing the tar. The orthodox methods in use do not completely effect the second object, as a considerable portion of the tar is present in the form of innumerable minute globules of tarry matter, each one of which contains a small volume of gas, and it is necessary to subject these tarry vesicles to some degree of friction in order to break them up, and thus effect their removal, the treatment which they receive in the ordinary condensing plant not affording sufficient friction. The apparatus for effecting this friction is generally some form of washer, such as Livesey's, or Walker's, usually fixed at the bottom of the scrubber, as described under that apparatus, or by the employment of the condenser of Pelouze and Audouin.

As the substances to be removed by condensation for the most part deposit themselves naturally as the crude gas gets cool, no complex apparatus is necessary. All that is required is a length of pipe in which the gas may cool down from about 150° F. (the temperature at which it leaves the hydraulic main) to about the normal temperature of the atmosphere; but before proceeding to describe the different forms of apparatus employed for this purpose, it will be necessary to revert to the means to be adopted to retain the illuminating hydrocarbons in the gas, and incidentally the treatment to which the gas should be subjected before entering the condensers.

It was previously remarked, that the tar thrown down in the hydraulic main consisted of impure hydrocarbons, and it has been shown by the late Rev. Mr. Bowditch and

others that the hydraulic main tar, which is of a very heavy character, if allowed to travel or come in contact with the gas, possesses the property of robbing the latter of its lighter and light-giving hydrocarbons; so, in order to avoid this, the tar which is deposited in the hydraulic main should be run off from the bottom of the latter, and deposited in the tar well, the gas travelling by a separate main at a higher level, the latter being joined to a pipe carried with a gradual inclination round the inside of the retort-house (known as the foul main), and from thence to the condenser; the gas would thus travel with the lighter tars, which are deposited after leaving the hydraulic main, and if arrangements are made for taking off the tar when the temperature falls to about 100° F., and the gas travels slowly, it is believed that the deposition of naphthalene is prevented, and the illuminating power increased by the abstraction of some of the illuminating matters from the tar. Further, in order to avoid any contact of the gas with the heavy tar, the hydraulic main should be supplied with ammoniacal liquor, all tar as deposited being at once got rid of as described; this will prevent the gas having to bubble through the column of tar as is ordinarily the case, with the consequent absorptive action of the thick tar.

After being deprived of the heavy tar, the process of condensation should be performed *very slowly*, and the gas be not allowed to cool below 50° F. If condensation is carried beyond this, there is a risk of some of the lighter hydrocarbons being thrown down, and the gas reduced in illuminating power accordingly; for this reason the condensing plant should be under complete control, by the provision of suitable bye-pass valves and connections, so as to regulate the amount of cooling according to the temperature prevailing. It is necessary to have thermometers inserted in the inlet and outlet of the condenser for the purpose of ascertaining the temperatures at any moment.

Condensers are divided into two classes: atmospheric condensers and water condensers, according to the cooling medium employed.

Atmospheric condensers comprise the ordinary vertical, the horizontal, the annular, and the battery condenser, the principal water condensers being Livesey's, and Morris and Cutler's.

The vertical atmospheric condenser is shown in fig. 12, and consists of a series of vertical pipes attached to a cast-iron box or cistern at the bottom, and connected in pairs by semicircular bends at the top. The cast-iron cistern is provided with a series of midfeathers, which dip to a certain depth in liquid, thus forming a seal, so that the gas is forced to pass up one pipe and down the next right along the series; the condensed products are deposited in the cistern, from whence they flow to the tar well.

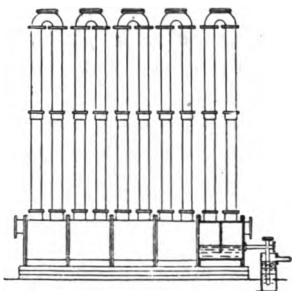


FIG. 12.

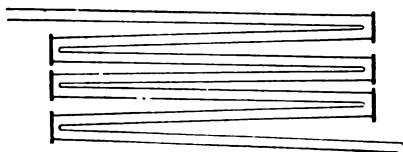


FIG. 13.

Condensers on the atmospheric plan act by transmitting heat from the gas and vapours within, to the external air in contact with its outer surface, so that the gases and vapours are cooled so as to separate the one from the other.

The horizontal atmospheric condenser is shown in fig. 13,

and consists of a series of pipes laid in a horizontal direction, and with a slight fall; the gas generally enters at the top, and leaves at the bottom, of the apparatus, whence the condensed products also flow away by reason of the slight amount of fall previously alluded to. The outlet pipe is sealed in a seal-pot, so that the condensed products flow away to the tar well automatically without the gas escaping, this device being commonly applied when we wish to get rid of liquid products without allowing gas to escape.

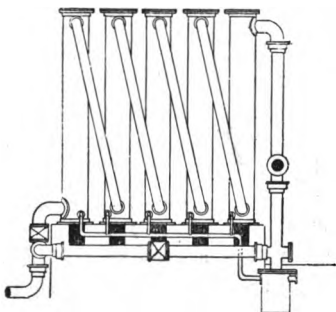


FIG. 14.

The annular condenser (fig. 14) is an extremely efficient instrument, and consists of a series of large pipes placed in a vertical position, each pipe enclosing a smaller pipe, which is open to the atmosphere, the two pipes thus forming an annular space through which the gas is caused to pass. Other pipes, placed diagonally, connect the top

and bottom of the condensing columns alternately. By this arrangement the gas passes through the annular space always in the downward direction, whilst the current of air which is produced by the heating agency of the hot gas, moves upwards through the inner air pipe.

The bottom of the inner or air pipes should be provided with butterfly valves, so that in cold weather the air-draught may be regulated so as not to reduce the temperature to too great an extent. A small pipe is connected to the bottom of each column to carry away the condensed products.

The battery condenser (fig. 15) consists of an oblong

vessel 12 to 24 inches wide, 12 to 18 feet high, and of varying length. It is divided internally by mid-feathers, placed at distances equal to the width apart, extending to within a few inches of the top and bottom of the chest alternately, the gas passing from the inlet up and down each division to the outlet. In order to increase its condensing power, small tubes of about 2 inches diameter pass from side to side of the vessel as shown. The air is capable of freely circulating through these tubes, and this helps to cool the gas; they further serve the purpose of breaking up any tarry particles.

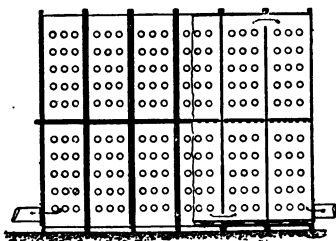


FIG. 15.

The water condenser possesses great advantages over the atmospherical condenser, as it admits of easy regulation, while the cooling agent (water) is much more powerful than that employed in the ordinary or atmospheric condenser, viz., air. By the employment of water we are enabled to neutralize the great variations which occur in the external temperature, and of adequately meeting the variations in the make of gas by the simplest means. Water has a far greater power of absorbing heat—in other words of cooling—than air has.

Peclet gives the following as the results of his experiments on the relative efficiency of water and air as cooling agents.

Excess of temperature in the gas.	Quantity of heat lost by a square unit of exterior pipe surface.	
	When radiating in air.	When radiating in water.
For an excess of 10 degrees .	8	88
" " 20 " .	18	266
" " 30 " .	29	5,353
" " 40 " .	40	8,944
" " 50 " .	53	13,437

A water condenser of an excellent kind, the invention of Mr. G. Livesey, has been long employed at the South Metropolitan Gas Company. The condensing pipes are placed in a tank of water divided into separate channels, all on one plane, in which the pipes are led backwards and forwards for several turns, with the water flowing in an opposite direction to the gas in the pipes. In this way the cool entering water comes first in contact with the gas pipes at their outlet from the tank, and becomes gradually warmed in the subsequent winding channels in proportion as it reaches the other end of the tank, where the gas enters at a high temperature from the retort-house. The temperature of the water, as also that of the gas, can be kept at a steady point by simply increasing or diminishing the admission of water according as it is desired to lower or raise the temperature of the tank.

Morris and Cutler's condenser consists of a rectangular cast-iron tank provided with a series of division plates, which divide it into a series of channels through which the gas is caused to travel alternately from end to end. Through each channel a number of small wrought-iron pipes are fixed, in which water is made to flow in the opposite direction to the flow of gas. The pipes are so arranged that they come into direct contact with the gas,

so that they not only cool the latter, but, in addition, subject it to a certain amount of friction.

The amount of condensing surface required, necessarily varies with the quantity of watery vapour and tar, in the crude gas. In the case of Newcastle coal, which yields a comparatively small quantity of water, say 12 gallons to the ton, an atmospheric cooling surface of 5 superficial feet per 1,000 cubic feet of gas made per day would probably be sufficient. Derbyshire coal yields about 26 gallons of water per ton of coal, so that gas from this coal would require a proportionately larger amount of cooling surface, about 10 superficial feet of cooling surface per 1,000 cubic feet.

By the time the gas has reached the outlet of the condensers, it will have deposited from 10 to 13 gallons of tar, together with from 13 to 20 gallons of water, holding more or less ammonia in solution, per ton of coals carbonized.

Condensers are usually made of cast-iron, although wrought-iron foul mains and annular condensers are now very general.

Pelouze and Audouin's condenser differs in principle from those just described, its object being to break up the suspended tarry particles in the gas. Fig. 16 shows the apparatus, as manufactured by Messrs. R. and J. Dempster, Limited, of Manchester.

The apparatus consists of an outer cylindrical cast-iron chamber, provided with the usual inlet for gas, and outlets for gas and the products of condensation, and contains a cylinder of perforated sheet-iron, which constitutes the condenser. The sides of the condensing chamber are two thin sheets of iron, having a concentric space between. The inner sheet is perforated with holes one-twentieth of an inch in diameter, and the outer with slots of a larger size, the outer sheet being so arranged as to offer a

blank surface opposite the small holes in the inner sheet. The passage of the gas through the apparatus is shown by

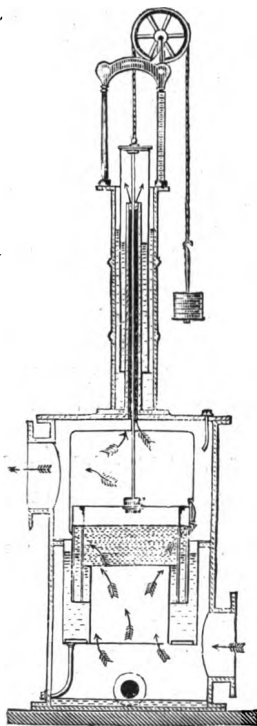


FIG. 16.

the arrows. On ascending into the cylindrical chamber and passing through the perforations, the gas is formed into jets, which strike against the solid surface sheet placed close to the perforated plates. In passing through the holes the liquid molecules are wire-drawn, and therefore brought into close contact with one another, the action being completed by contact with the solid surface upon which the tarry matter is deposited, from whence it flows down the surface of the plate into a tar pan underneath the apparatus, and from thence to the tar well.

The condensing cylinder, properly balanced, is capable of acting as its own regulator. For this purpose it moves in a hydraulic seal, which allows of the closing of those gas passages which are not required to be in action. When the pressure increases, i.e., when there is an increase of gas, the cylinder rises, and a large number of openings are uncovered to allow the gas to pass through, thus adjusting itself to night and day, or to winter and summer workings.

CHAPTER VIII.

THE EXHAUSTER.

PLACED between the condenser and the scrubbers is the apparatus known as the exhauster, which plays a very important part in the economy of a gas-works. The exhauster is employed for the purpose of withdrawing the gas from the retorts as fast as it is produced, and propelling it onward through the remainder of the apparatus through which the gas has to pass on its way to the gas-holder. On the inlet side of the exhauster, therefore, there is a vacuum sufficient to overcome the resistance of the seal in the hydraulic main, and any resistance due to friction in the condenser, which may be taken at $2\frac{1}{2}$ inches, while, on the outlet side, there will be a back pressure, as it is termed, of, roughly speaking, about 24 inches, viz., 2 inches due to the resistance of the scrubber, 14 inches due to the purifiers, and 8 inches to the gas-holder and meter; but these figures will necessarily vary, according to the character of the plant and other circumstances. Without an exhauster the whole of this resistance would be exerted against the gas in the retorts, which would have the effect of causing the latter to leak badly; a large proportion of the gas would in fact find its way into the furnace through the cracks and joints in the retorts.

When the exhauster is at work, the pressure on the retort is only that due to the seal of the dip pipe, which, as a rule, is only a few tenths of an inch; but with the

exhauster out of action the liquid in the hydraulic main rises up the dip pipe to a considerable height, and through this accumulated pressure the gas has to force its way. The consequence is, that it takes an easier course, *i.e.*, through the cracks and joints of the clay retorts: clay retorts, although being practically gas tight under a few tenths of an inch of pressure, are not so under the pressure which results when the exhauster is out of action; the consequence being that there is great leakage, as just described. The same result does not take place when iron retorts are employed, as the metal of which such retorts are made is more homogeneous than fire-clay: it is not so necessary, therefore, in the case of iron retorts to employ an exhauster, as there is not the same amount of leakage. In addition to the loss of gas by leakage, there is another reason for the employment of the exhauster, *viz.*, when gas is subjected to pressure in the retorts, some of the richest constituents of the gas are deposited on the walls of the retorts, the deposit being technically known as carbon or "scurf:" this carbon takes away from the retort space, and consequently must be periodically removed, which means retorts standing idle for a time. It also means an increased consumption of fuel, owing to the carbon being a non-conductor of heat: further, the removal of the scurf, as ordinarily practised, *viz.*, by chisel bars, is very destructive to the retorts themselves.

Exhausters are divided into two classes, rotary and reciprocating. The exhausters of Jones, Laidlaw, and Beale are on the rotary principle, while Methven's, Anderson's, and Dempster's are reciprocating. The two last-mentioned exhausters are similar in principle, the apparatus essentially consisting of what may be called a gas-pump, having a strong resemblance to an ordinary steam cylinder, with its accompanying piston and piston-rods, slide-valve, ports, etc.

Fig. 17 shows a small type of pump exhauster, as manufactured by Messrs. R. and J. Dempster. It is made on the same principle as an ordinary pump, the piston-rod of the steam cylinder being coupled direct to the gas cylinder by means of a cast-steel bow.

The majority of exhausters met with in gas-works, however, are of the rotary class, those which work on the principle originally devised by Mr. Beale being the most numerous.

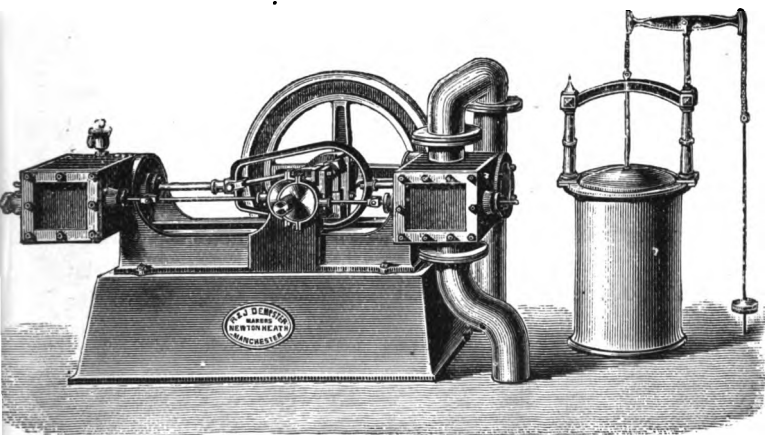


FIG. 17.

Beale's exhauster, as manufactured by Messrs. Gwynne and Co., is shown in figs. 18, 19. The apparatus consists of an outer cylinder bored out, provided with inlet and outlet pipes, and having a roll or drum working eccentrically inside it, the diameter of the drum being two-thirds that of the outer case. The axis of the drum is placed at such a level in relation to the outer case that the drum, when revolving, is in contact with the bottom of the outer cylinder, but does not rest upon it.

The drum revolves upon a shaft which passes through

stuffing-boxes fixed on the end plates of the outer cylinder, where it rests on two gun-metal bearings, one at either end of the outer cylinder. The drum has slots cut in it on each

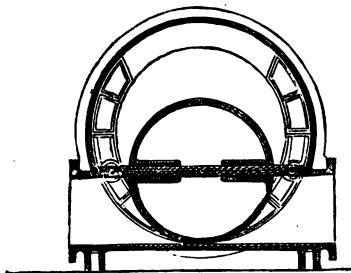


FIG. 18.

side, and through these slots freely slide two diaphragms or blades, which, being planed and faced, slide over one another, and thus form one double diaphragm, which varies in width according to the relative position of the two single diaphragms to each other. The ends of

these slides have steel-cased pins which work in wrought-iron segments turning in grooves sunk in the end covers of the outer cylinder, so that when the drum revolves out of the centre of the cylinder, the diaphragm being attached to the

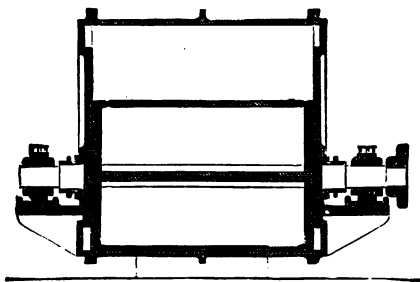


FIG. 19.

segments, the slides are drawn in and out, and so draw in the gas on one side of the cylinder and discharge it on the other by continuously sweeping the walls of the outer cylinder, and as the segments travel in a circular course,

concentric to the outer cylinder, the outer edges of the diaphragms are always maintained in the same relative position to the inner walls of the cylinder by the aid of the sliding arrangement previously alluded to. The slides are kept in close contact with the inner walls of the cylinder by means of a T-shaped strip having a flat spring at the back, the web of the T and the spring being recessed into a groove in the edge of the slide. The drum is driven either direct from a steam-engine, which is coupled on to the same shaft, or by means of belting from a separate source of power. Each revolution of the drum and slides draws in and discharges double the contents of the cylinder, minus the contents of the drum and slides.

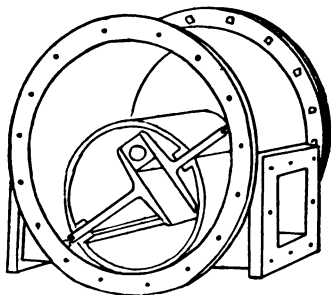


FIG. 20.

Fig. 20 shows Beale's exhaustor, as manufactured by Messrs. B. Donkin and Sons. It will be seen that in this form of exhaustor, a rotating block is fixed in the centre of the exhaustor, which is carried on a horizontal fixed pin, and having two guides on the slide which engage with the rotating block, and guide the slide independently of the casing.

The chief improvement claimed for this latter form of exhaustor is that the slide is guided from the centre of the exhaustor, where the velocity is very low, instead of from the periphery, where the velocity is high; the difference being as 15 to 1 for the same number of revolutions.

A later development in exhaustors by the same firm is utilizing the space occupied by the internal cylinder, as shown in fig. 21.

Waller's Three-Blade Exhauster.—It is claimed for this form of exhauster that with three blades it will deliver one-third more than the Beale's exhauster with the same size cylinder, and at the same speed, the contents of the cylinder being discharged three times in each revolution, against twice in the latter; the oscillation is thereby reduced in proportion (and still further when four blades are used). The blades working on a central pin are radial with the cylinder, and work smoothly round its circumference without ring or segments, instead of, as formerly, being eccentric

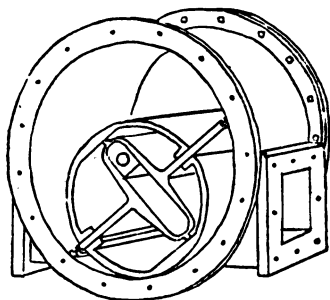


FIG. 21.

to the cylinder, and requiring much friction and power to move them round with the heavy ring or segments at the ends of the blades. The blades being supported on a central pin are better balanced, and there is an absence of that "falling over" movement when turning the centre twice each revolution, so common to the one or two-bladed

exhauster, necessitating the use of a heavy fly-wheel to counteract the effect; for the same reason, this exhauster can be run at a higher speed with steadiness and without increased friction. The exhauster is made with or without combined engine.

The cylinder is made as usual with two branches, and either can be inlet or outlet. The covers are recessed for ends of the roller, and have a boss for a central stud or, in large sizes, for a central pin going through both covers. This stud, or pin, is of steel, and hollow to admit of oil being injected to lubricate the joints of the blades. The roller is open at one end and solid at the

other (but in the larger sizes open at each end), the ends fit in the covers, and round the circumference of the roller are steel slotted rollers to carry the blades and swivel with them to suit the varying position. Neither rings or segments are used in this exhauster. The blades each have

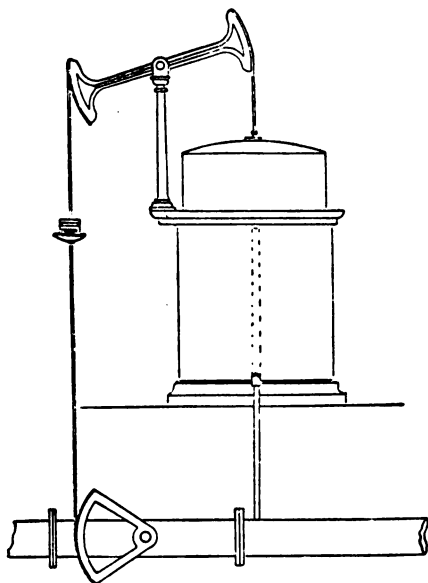


FIG. 22.

two hinges fitting between each other, making together a continuous bearing on the central pin.

In the working of exhausters it is necessary to guard against both excessive and insufficient exhaustion. Excessive exhaustion means the drawing in of air and furnace gases through the retorts, with a consequent depreciation of the illuminating power of the gas; insufficient exhaustion

means leakage, and loss of illuminating constituents as previously explained.

Owing to the manner in which the retorts are charged, the production of gas varies from hour to hour; the pressure of steam and amount of back pressure also vary; consequently, it is not practicable to work the exhauster satisfactorily so as to avoid the excesses previously referred to, without some special regulating arrangement for controlling the speed so as to adapt it to the varying conditions alluded to. The plan generally adopted is to connect the inlet and outlet pipes of the exhauster with a smaller pipe, known as a bye-pass main, in which is inserted a throttle valve, to the spindle of which is fixed a weighted quadrant. This is connected by a series of rods and chains to the lever arm of a gas governor, which is in connection with a pipe coming direct from the hydraulic main, as shown in fig. 22; the bell of the governor is counterbalanced and weighted so as to maintain a certain exhaust; should this be exceeded, the bell of the governor falls, which causes the throttle valve in the bye-pass main to open, so that a portion of the gas which has passed through the exhauster is "churned" over again, which compensates for the extra vacuum resulting from the exhauster running at too high a speed, by giving it more work to do; but this method possesses the defect that, should the exhauster be running too slow, then it is ineffective.

In order to get over this difficulty, it is customary in many works to attach the governor previously described direct to the steam-valve of the engine, so as to control the speed of the latter according to the make of gas. Messrs. George Waller and Co. make a governor, specially adapted for this work, which performs its duty admirably.

The exhauster should always be provided with a bye-pass flap valve in case of a sudden stoppage. The valve,

when the exhauster is at work, is closed, but on the gas having no vent through the exhauster, the excess of pressure forces it open, so that the gas goes forward as usual.

It is advisable to have three gauges fixed in the exhauster house: one leading from a pipe in direct communication with the hydraulic main, one on the main inlet of the exhauster, and another on the outlet of the same. It is necessary to note that the pressure (or vacuum) in the hydraulic main does not tell us the pressure within the retorts, as the latter depends upon the extent to which the dip pipes are sealed in the liquid contained in the hydraulic main. Thus, supposing that the dip pipes are sealed in the liquid contained in the hydraulic main to a depth of two inches, and that the gauge in communication with the hydraulic main shows one and a half inch of vacuum, then the retorts would be under half an inch of pressure.

The amount of "pull" exerted by the exhauster on the inlet side, so as to withdraw the gas from the retorts, is known as "vacuum," while the resistance on the outlet side is spoken of as "back pressure."

As remarked at the beginning of this chapter, the exhauster exercises an important effect on the economical working of a gas-works, and it should be so manipulated as to enable the gas to be generated in the retort under the least possible pressure consistent with not drawing in furnace gases.

The following is a brief summary of the advantages which attend the employment of this apparatus:—Increased production of gas per ton of coals, with an increased illuminating power; longer life of the retorts; decreased consumption of fuel.

CHAPTER IX.

PURIFICATION.

(Abstraction of the Ammonia.)

THE substances present in the crude gas which are regarded as impurities, in addition to the tarry matters and aqueous vapour deposited during the process of condensation, are:

Carbonic acid (CO_2),

Ammonia (NH_3),

Sulphuretted hydrogen (SH_2),

Bisulphide of carbon (CS_2), and other compounds of sulphur.

Before proceeding to discuss the methods by which these impurities are removed from the crude gas, it will be advisable to say a few words concerning their properties, and the reason for their removal.

Carbonic acid (CO_2) is a colourless, odourless gas, which will not burn or support ordinary combustion. It has a slight acid taste and reaction. Under ordinary conditions of temperature and pressure water will dissolve its own volume of the gas, *i.e.*, at 60°F . and 30 inches, a pint of water will dissolve a pint of gas. But a change in temperature or pressure will result in a change in the quantity of gas dissolved, so that if the water in the illustration just cited were cooled down to 32°F ., the pint of liquid would then dissolve nearly a pint and three-quarters of the gas.

Carbonic acid is chiefly objectionable on account of its

exercising a lowering action on the illuminating power of the gas.

Sulphuretted hydrogen (SH_2) is a colourless gas, having a sweet taste and the odour of rotten eggs, and when present in large quantity is poisonous. It is freely soluble in water, which dissolves 4.37 times its bulk of the gas at 23°F . It has a feeble acid action, and burns in air or oxygen, producing SO_2 or S, according as to whether there is an excess or a deficiency of air.

In addition to its poisonous properties SH_2 acts prejudicially by causing all bright metal work, such as picture frames, to become tarnished.

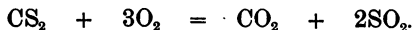
Ammonia is a colourless gas, with a characteristic pungent odour and strong alkaline reaction, and is extremely soluble in water. The gas does not burn, nor does it support combustion in the ordinary sense of the word. If, however, it be ignited in oxygen, it readily burns with a non-luminous flame, forming water and liberating nitrogen.

Being of an alkaline nature it is capable of neutralizing the acid bodies, CO_2 and SH_2 , and advantage is taken of this property in the washers and scrubbers.

The presence of ammonia in coal-gas causes destruction of any brass or copper work, such as the index wheels of meters, gas fittings, etc., with which it may come into contact, hence the necessity for its removal.

Carbon disulphide (CS_2) is prepared by passing the vapour of sulphur over charcoal heated to redness. On making the resulting product flow through a condensing-tube, an impure form of carbon disulphide is obtained. Carbon disulphide is a colourless, heavy, and extremely volatile liquid. The commercial product has a very foetid and repugnant smell; but when pure it has a sweetish, ethereal odour, and an acrid, pungent taste. It is highly refractive, and has a specific gravity of 1.29. Water dissolves about

.1-1000th of its volume of the bisulphide, and yields it up again on distilling; the solution possessing a burning taste, with the odour of the bisulphide. Many substances insoluble in water are soluble in this liquid—such as sulphur, phosphorus, iodine, caoutchouc, fats, and oils. Carbon disulphide boils at 46° C. Its vapour, when mixed with three times its volume of oxygen, ignites with explosion; forming sulphurous and carbonic acid gases, thus:



The vapour of carbon disulphide, when mixed with nitric oxide, burns with a blue flame, which is very rich in rays of high refrangibility, and has, on this account, been used in photography. On passing the vapour through a tube heated to bright redness, it is partly resolved into its elements; carbon depositing, and sulphur passing off with the undecomposed portions. The vapour of bisulphide of carbon has an excessively low igniting-point, and will take fire at a temperature of 300° F. (149° C.). But the trace present in coal-gas is so minute that it could not affect its point of ignition; besides which Dr. Frankland has shown that even the smallest trace of ethylene in a gaseous mixture which contains the vapour of bisulphide of carbon destroys this great inflammability.

“The formation of the bisulphide of carbon vapour found in coal-gas is due to the direct action of sulphur vapour upon the red-hot carbon. If powdered charcoal or coke be mixed with powdered sulphur, and the mass heated, sulphur vapour distils off, and no bisulphide of carbon is produced, because the sulphur has all volatilized before the carbon is in a sufficiently heated condition to bring about combination; and if the sulphur in the coal were in the free state, the same thing would happen. When coal is put into the hot retort, the portions in contact with the sides are rapidly raised in temperature, and the

sulphur which is liberated by the breaking up of the disulphide of iron, pyrites or 'brasses,' vaporizes, and combines with free hydrogen to form sulphuretted hydrogen. But by the time the pyrites in the centre of the mass of coal are sufficiently heated to yield sulphur vapour, the outer surface of the partly coked mass is at a temperature high enough to form with it small traces of bisulphide of carbon; and the higher the temperature used, the more of the 'sulphur compounds other than sulphuretted hydrogen' are produced" (Professor Lewes).

In the following table, obtained from experiments made by Mr. Lewis T. Wright, this is shown very clearly; the yield of gas per ton of coal being taken to give an idea of the temperature, while the grains per 100 cubic feet of sulphur compounds in the gas, are after purification from sulphuretted hydrogen—the same coal being used in each case:

Yield of Gas per ton.	Sulphur per 100 cubic feet.				Grains.
6,893	.	.	.	.	13·9
8,370	.	.	.	.	19·1
9,431	.	.	.	.	26·7
10,772	.	.	.	.	36·9
11,620	.	.	.	.	44·1

The injurious action of CS_2 in coal-gas is due to the fact that sulphuric acid is one of the products of its combustion, but the actual amount of carbon bisulphide generally present in purified gas is exceedingly small, and there is a great difference of opinion as to the effects produced when coal-gas containing CS_2 is burnt. The following are the views of Professor Lewes, who has minutely investigated the question. (See "Journal of Gas-lighting," February 20th, 1894):

"In considering the effect of these sulphur compounds in the products of combustion, it must be borne in mind

that, when coal-gas is burnt the sulphur is liberated in the form of sulphur dioxide; and many most misleading statements and ideas have gained ground as to the quantity of this which becomes converted into sulphuric acid in the atmosphere. My own experiments, as well as those of Mr. Harold B. Dixon, all prove that when traces of sulphur dioxide, as minute in quantity as those which are given off in the combustion of gas, are present in the air, they show no tendency to oxidize to sulphuric acid, even though the air is highly charged with moisture, unless the temperature falls to such a point that water is deposited from it. This water then takes up the sulphur dioxide, which slowly becomes oxidized to sulphuric acid. For this reason it is perfectly possible to find traces of sulphuric acid and sulphates upon window-panes where the cold air outside has caused moisture to condense on the windows; and the same action will take place where you have ammonia or other alkaline substances present in the air or dust, fixing the sulphurous acid. But it is manifestly incorrect to suppose that this action goes on unless the temperature of the room has fallen to the condensing point of the water vapour; for, if this did take place, even with the highly-purified London gas, there is not a sitting-room in London in which the draperies would not become rotted in a very short space of time, as the smallest deposit of sulphuric acid, no matter how dilute, would, by slow and cumulative action, become sufficiently strong to burn away the fabric. The test of time has shown the fallacy of any such injurious action.

“In order to prove the deleterious effects of this hypothetical formation of sulphuric acid, certain observers have brought forward many experiments to show that, in passing the air through absorbing solutions, sulphates could be detected in them in small and varying quantities. This, however, certainly does not prove that sulphates

were present in the air, as, directly the sulphur dioxide is absorbed by the liquid, the oxidation to sulphuric acid takes place with considerable rapidity. It is this that has given rise to wrong deductions from the observed facts of sulphuric acid, either free or in combination, being found in wetted fabrics, or on moistened plates or liquid absorbents exposed to the air of rooms in which gas has been burnt, also on lamp-glasses and in ventilating-tubes, especially in towns where no limit is placed on the amount of sulphur present in the gas.

"It has also been considered a proof of the formation of sulphuric acid from the products of combustion of gas containing sulphur compounds, that dust collected in a room in which such gas is being burnt contains small quantities of sulphates. But here again several important factors of error have been overlooked. The dust which is found in a room has not been formed in that room, but has filtered in from the outside air, under the sashes and other openings; and it must, of necessity, contain sulphur compounds, which have been produced by the fixation of the sulphur produced by the burning of coal and coke, by the ammonia and other alkaline bases present in the air. An analysis of dust from rooms in which no gas has been burnt will also show the presence of these bodies in as large quantities as from the rooms in which gas has been consumed in very considerable volume. Dust collected in my study at Greenwich, in which gas is very freely burnt, gave 3.05 per cent. of sulphur as sulphates; while dust collected in an attic in a disused portion of the same building, in which there has never been a gas-fitting, gave 4.4 per cent. This mistake has been caused by the fact that rain-washed dust collected on exposed outside sills often contains only a small percentage of sulphur. The closeness and oppressive feeling which can be distinguished in a room that is not properly ventilated, when gas is

being burnt, is not due to the presence of sulphur compounds, but to carbon dioxide, and to the traces of the products of incomplete combustion. It is also partly owing to the organic emanations from the bodies and lungs of the occupants of such a room being unable to rise into the zone of highly-heated air which exists above the gas-burners in the room, and so being kept down to the level from which the air for respiration is being drawn."

As remarked under condensation, the first stage of the purifying process begins when the crude gas leaves the retort and travels along the hydraulic main, a partial deposition of the tarry and aqueous vapours taking place, together with a small portion of the ammonia which is absorbed by the condensed aqueous vapour, but very little purification is effected here, however, as the gas is still in a heated condition, and it is not until its passage through the condenser, where it becomes reduced to the normal temperature, that purification proper can be said to commence. Passing through the condenser nearly the whole of the tarry vapours previously held in suspension are deposited, collecting as liquid tar, together with a quantity of weak ammoniacal liquor, about one half of the total ammonia in the gas being deposited by the time the latter reaches the outlet of the condensers.

It is of the utmost importance that the condensing power should be properly proportioned to the make of gas, for, if the temperature of the gas is not properly reduced before it enters the scrubbers, these vessels will not do their work efficiently, and, as a consequence, extra work will be thrown upon the purifiers proper. In addition to being cooled down to the normal temperature, the gas should be quite free from suspended tarry particles, which would tend to block up and impede the action of the washers or scrubbers.

The last-mentioned plant is employed for the removal

of the remainder of the ammonia contained in the gas, and when properly manipulated should also remove considerable quantities of CO_2 and SH_2 . These impurities are found in the crude gas to the extent of from 2.5 to 3 per cent. of CO_2 , and from 1 to 2 per cent. of SH_2 , a portion being absorbed by the weak ammoniacal liquor produced in the hydraulic main and condensers. Ammonia is removed in the washers and scrubbers by the agency of water, which at a temperature of 60°F. , and under a barometrical pressure of 30 inches, is capable of absorbing 783 times its own volume of ammoniacal gas, the power of absorption *decreasing* with an increase of temperature, and *vice versâ*; so that at a temperature of 183°F. it loses all power of absorption. As a consequence, the lower the temperature at which the gas enters the scrubbers, and the colder the water, the more effective will be the action of the apparatus, but care must be taken not to have the temperature too low, or there will be a risk of injuring the illuminating power, so it is advisable not to allow the gas at the inlet to the scrubbers to be below say 50°F. , or to meet water at a lower temperature than 50°F. The apparatus in which the water is employed may be divided into washers, scrubbers, and a combination of the two, known as "washer-scrubbers."

By the term washer is generally understood that form of apparatus in which contact between gas and liquid is obtained by forcing the former through a number of seals of indeterminate depth; the same process of washing being effected in a scrubber by means of a large area of wetted surface. The object of the washer is to remove a portion of the ammonia, together with some CO_2 and SH_2 , and the whole of the suspended tarry particles which have not been got rid of in the condensers, so that the gas may be free from tar when it enters the scrubbers.

The washer should always be employed in conjunction

with a scrubber, the gas passing through the washer first.

Washers generally constitute a separate apparatus, but they are sometimes placed at the bottom of "tower scrubbers," forming a portion of that apparatus. Every description of washer throws a certain amount of back pressure, according to the depth of seal through which the gas has

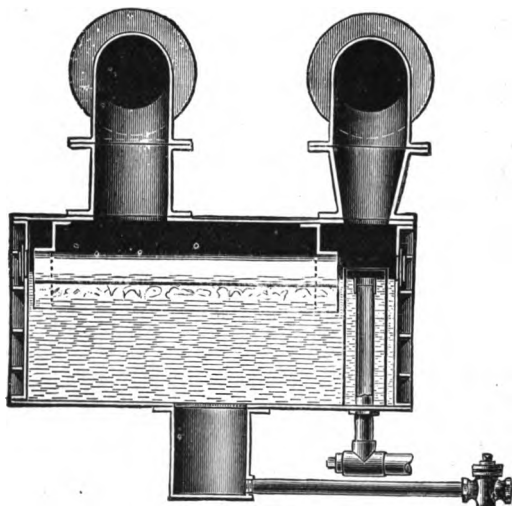


FIG. 23.

to force its way; the amount of this pressure varies from 1 to about 4 inches.

The principal washers in general use are those of Anderson, Livesey, and Walker. The washer of Mr. G. Anderson consists of a cast-iron outer vessel containing a number of trays, having on their under side a series of serrated bars extending from side to side; these dip into water or liquor, as the case may be, with the result that

the gas, in passing through the serrations, is split up into minute globules.

The apparatus is provided with an overflow, by means of which the pressure can be regulated by raising or lowering the overflow. The washer is supplied with the weak liquor from the condenser, which is run in at the top and flows from tray to tray, gradually increasing in strength until it reaches the bottom, where it flows away by a sealed overflow.

The washer invented by Mr. George Livesey effects the greatest possible subdivision of the gas into minute bubbles in contact with liquor. The gas is caused to pass through perforated plates of wrought iron with holes one-twentieth of an inch in diameter, placed so that there are about thirty in a superficial inch of plate. Figs. 23, 24, 25 show three different views of this apparatus, as manufactured by Messrs. R. and J. Dempster, Limited, of Manchester.

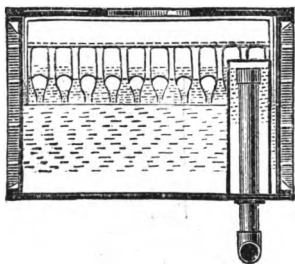


FIG. 24.

Fig. 20 shows a longitudinal section of washer, illustrating the method of attaching the tubes to the top compartment. The syphon pan is fixed to the bottom to receive the heavy tar, which is run off daily by opening the tap, shown at the end of the pipe. Fig. 24 shows a cross-section of washer, illustrating the method of placing the tubes, and also shows the outlet pipe for taking off the liquor, the seal of which is adjusted by a long screwed socket. Fig. 25 does not require any description.

It will be seen from a reference to the above figures that the washer consists of a rectangular cast-iron box, the upper part being formed into an inlet chamber and one or

two outlet chambers, according to its capacity; to the lower flanges of this inlet chamber is securely fastened a series of rectangular wrought-iron tubes, to which wrought-iron perforated plates are attached, turned down at the sides till they dip into the liquor, which is kept at a certain level, the perforations being one-twentieth of an inch diameter, and one-fifth of an inch apart. The interior of the

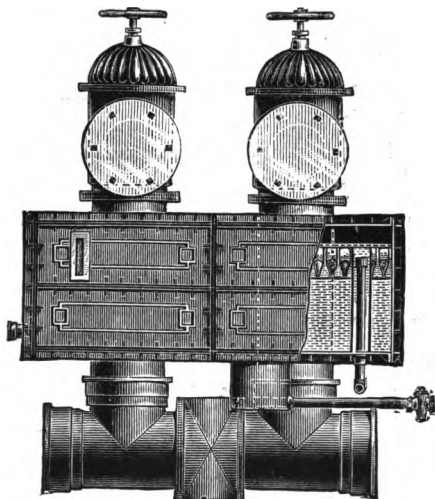


FIG. 25.

tubes is in free communication at the ends with the outer chambers, but the spaces between the tubes at the ends are securely closed up. The gas has free access from the inlet chamber to these intermediate spaces, passing down them so as to depress the liquid, until the gas escapes through the inclined portion of the perforated plate into the first space, which is filled with liquor, up through which it bubbles until it comes in contact with the horizontal part of the perforated plate, carrying some of the

liquor with it to the upper surface of these plates. The bubbles of gas pass through this liquor into the tube

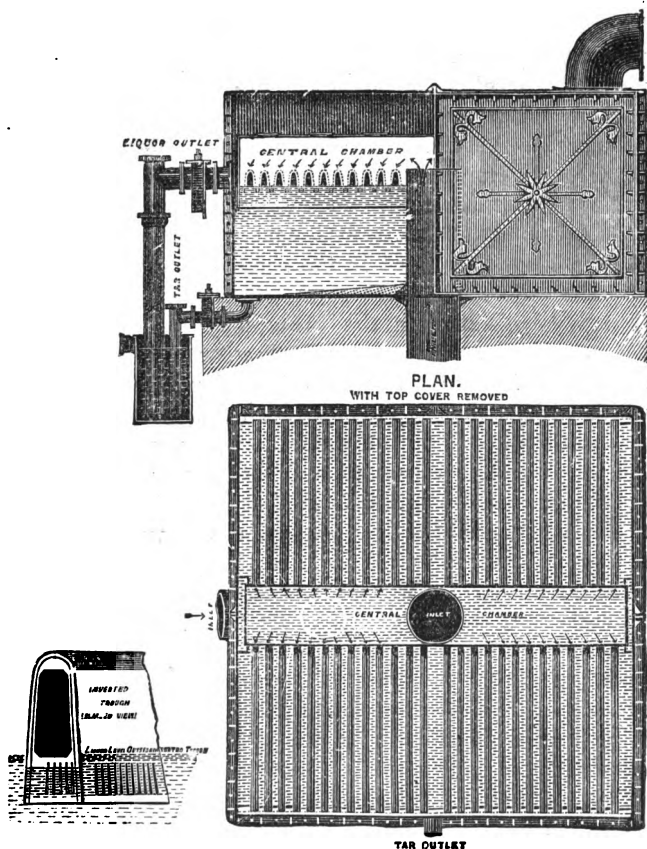


FIG. 26.

space, and convert the surface into foam, which flows along with the gas into the outer chambers. The liquor

H

escapes from the washer by means of overflow pipes, as shown; the overflow pipes have a long thread on the top, and a socket, by which the level of the liquor is adjusted. The liquor supply is brought in at a convenient place at the lower part of the washer, such supply flowing either from the scrubber or another washer placed 6 inches higher. Where two or more washers are used, they should be placed so that the liquor will flow from the last to the first. A difference of 6 inches in the relative levels will suffice for this, and where a scrubber is in use, the washer should be placed below it, so that pumping may be avoided. Glass windows are fixed in the sides of these washers, at opposite ends of the tubes, so that the bubbling of the gas through the liquor in the tubes may be clearly seen. These washers work most effectively when they have nearly an inch of liquor above the horizontal perforated plates, which gives 3 inches of pressure. Special provision is made in the lowest part of the washer for the collection of the tar, which is separated and falls by gravity to the bottom, and is drawn off from that level, independently of the liquor, periodically. The use of this washer results in the total removal of all tar from the gas, together with large quantities of NH_3 , CO_2 , and SH_2 .

Walker's washer is shown in fig. 26. It consists of a cast-iron vessel, the bottom of which is covered with concrete, and the surface inclined towards the tar outlet, so as to facilitate the exit of the tar, the outlet for the liquor being fixed at a suitable height. The gas, passing in at the centre (or any convenient part) of the bottom of the vessel, enters a central chamber, from which branch off, on each side, a number of longitudinal passages or inverted troughs, closed at the far end, but open at the bottom. When the liquor is at its proper level, these are partly immersed, and in the part of the surface underneath the liquor are cut a large number of peculiarly

shaped slots. These are shown in the enlarged view, and extend regularly from end to end on each side of the troughs. The gas passes into the upper part of these troughs, and, by displacing the liquid, finds its way through the slots, and bubbles up in very minute streams to the surface of the liquid, from whence it passes to the outlet. The shape of the slots is such as to accommodate a considerable variation in the make of gas. As shown, the vessel forms a separate piece of apparatus, but, if required, it can be fixed to the bottom of a scrubber, and, when filled with strong liquor, it acts as a decarbonator.

The scrubber, however, is the apparatus most generally employed for removing the ammonia from gas, and differs from the washer in this respect: that in the washer the gas has to force its way through the liquid contained therein; while in the scrubber it is only brought into contact with the latter when

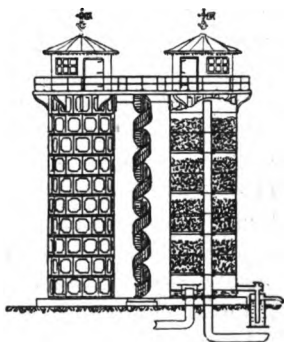


FIG. 27.

passing over the surfaces of pieces of coke, broken bricks, pebbles, boards, or other materials having a large area, and saturated with water. The "tower scrubber" is shown in fig. 27, and consists of a cast-iron cylindrical vessel, standing in height about six or seven times its diameter. It is divided into a number of compartments in which are placed cast-iron grids, which support the materials, each division having a manhole secured by a movable cover, for the purpose of entering the scrubber when required.

The material most commonly employed for filling the scrubber is coke, which entirely fills each compartment,

with the exception of a space of about six inches at the top of each layer.

In place of coke the scrubber is sometimes filled with thin wooden boards, about a quarter of an inch in thickness, set on edge, either perpendicularly or slantingly, and about three-quarters of an inch apart. The boards, which are about eleven inches deep, are arranged in tiers, in each of which the boards are differently set, a space of about an inch being left from the top of one tier to the bottom of the other.

These boards, although costing more in the first instance, are really cheaper than coke in the long run, as they never get choked with tar, and consequently never require renewing; whereas the coke soon gets choked, and so requires renewing at least every second year.

The gas enters the scrubber at the bottom of the vessel, and leaves it by the outlet pipe at the top, which occupies the centre of the vessel. By a suitable arrangement, a fine stream of water is caused to play upon the material, which consequently exposes a large area of wetted surface to the ascending gas, with the consequent elimination of its ammonia, the gas encountering the strong liquor at the bottom, and leaving the top in contact with clean water. The resulting ammoniacal liquor collects at the bottom of the vessel, and overflows through a seal pipe dipping into a seal pot to the liquor well.

The proper action of the scrubber depends, to a great extent, upon the material being thoroughly and equally wetted on every portion of its surface, and upon the whole of the tar being eliminated from the gas before entering the apparatus.

One method of supplying the water, or liquor, to a scrubber is by means of a pipe which passes through the top of the vessel, having smaller pipes pierced with holes radiating towards the circumference, and which are capable of revolving.

Another method is by the adoption of the contrivance known as Gurney's Jet, which consists of a jet of water under great pressure impinging on a small disc or button; this causes the water to be spread out in the form of very fine spray.

There is also the contrivance known as the "Tumbler" distributor, which is employed for the same purpose. In this apparatus water runs into a trough hung on pivots, and when a certain quantity has run in, it is made to over-balance and suddenly to discharge its contents through a seal box at the centre, on the top of the scrubber.

In order to get rid of the tar from the gas before it enters the scrubbers, it is advisable to fix a washer at the bottom of the apparatus as previously mentioned. Scrubbers are generally worked in pairs, the gas passing through both in succession.

The first scrubber is supplied with the weak ammoniacal liquor deposited in the hydraulic main and condensers, together with the liquor produced in the second, or clean-water scrubber (seal-cup liquor). This way of working enables the liquor to be concentrated, and also causes a certain proportion of the acid impurities CO_2 and SH_2 to be removed from the gas, owing to the affinity which exists between the alkali ammonia and the acid bodies CO_2 and SH_2 , with the consequent formation of ammonium carbonate and sulphide. It may be remarked here that about 80 per cent. of the ammonia in ammoniacal liquor is found combined with the feeble acids CO_2 and SH_2 , and as this ammonia can be expelled by boiling, it is commonly spoken of in gas-works as "free ammonia." The remaining 20 per cent. of ammonia in the liquor is found in combination with sulphuric, hydrochloric, and other acids; and as the resulting salts do not give off their ammonia on simple boiling, such ammonia is spoken of as "fixed" ammonia.

The following analysis by Professor Lewes will give an idea of the relative quantities in which these two descriptions of compounds exist in ammoniacal liquor :

				Grammes per litre.
Free	{	Ammonia sulphide . . .	3·03	
		„ carbonate . . .	39·16	
		„ chloride . . .	14·23	
Fixed	{	„ thiocyanate . . .	1·80	
		„ sulphate . . .	0·19	
		„ thiosulphate . . .	2·80	
		„ ferrocyanide . . .	0·41	

Of course, strictly speaking, the term “free” ammonia means a solution of gaseous ammonia, but in gas-works’ parlance it is the custom to call all the ammonia which can be liberated on simply boiling the liquor “free.”

By taking advantage of the affinity between ammonia and CO_2 and SH_2 , less work is required to be done in the purifiers proper, with a consequent economy in materials and labour charges. The combination of ammonia with CO_2 and SH_2 gives rise to two series of salts, one in which two volumes of nitrogen combine with two of the acid; that is, one molecule of ammonia (NH_3) combines with one molecule of carbonic acid (H_2CO_3) and produces one molecule of ammonium bicarbonate (NH_4HCO_3), or one molecule of ammonia combines with one molecule of SH_2 and produces one molecule of ammonium sulphhydrate (NH_4HS), and the other in which four volumes of nitrogen combine with two of the acid; that is, two molecules of NH_3 combine with one molecule of H_2CO_3 , or H_2S , to form one molecule of ammonium monocarbonate ($(\text{NH}_4)_2\text{CO}_3$, or ammonium sulphide respectively.

Now when employing ammonia as an agent for the removal of the impurities just referred to, the aim of the

gas manager would be to obtain the combination which requires the least ammonia, as, if the first series alone were formed, the ammonia would do double the amount of work in removing the other impurities, but unfortunately there is no means of securing this condition of affairs. It is found in practical working that 100 volumes of ammonia combine with $62\frac{1}{2}$ volumes of the two acids CO_2 and SH_2 , but not in equal proportions, as the CO_2 is always in considerable excess over the SH_2 , in the proportion, roughly speaking, of 50 : $12\frac{1}{2}$, the ratio varying with the strength of the liquor and the temperature at which it has been produced ; these figures refer to the liquor obtained from every portion of the gas-making plant when mixed together, as the liquor obtained in different parts of the plant will necessarily vary very much.

The amount of ammonia which is present in the gas derived from one ton of coal varies from about $5\frac{1}{2}$ to 8 lb., and, roughly speaking, this forms about one per cent. by volume, and as the acid impurities CO_2 and SH_2 , which are also present in the crude gas, are found, roughly, to the extent of about five per cent., it will be seen that there is not nearly sufficient ammonia to combine with the acids present, even under the most favourable conditions, if only once used ; if sufficient ammonia were formed or could be produced to combine with the whole of the CO_2 and SH_2 , the removal of all three would be easily and cheaply accomplished without the aid of any foreign material or elaborate purifying arrangements. It has for a long time been attempted to purify gas in closed vessels by means of ammonia. What is known as " Hill's process " has been in use for a long period at the Old Kent Road Works of the South Metropolitan Gas Company with this object. The process consists in heating ammoniacal liquor to a temperature a little below boiling point, which has the effect of driving the acid gases, CO_2 and SH_2 from their

combination with the ammonia leaving the latter in solution in the water, so that it may be used again in the washers or scrubbers.

The scrubbers also take out about two grains of CS_2 per 100 cubic feet.

In the second, or clean-water scrubber, clean water is admitted in the proportion of 2 to 3 gallons per 1,000 cubic feet of gas; the last traces of ammonia are the most difficult to remove, as the NH_3 then forms only a very small portion of the total volume, or in other words, it is largely diluted. The scrubber liquor obtained in this manner amounts to from 10 to 18 gallons of 10 ounce strength, the total quantity produced per ton of coals varying from 26 to 36 gallons of 10 ounce, according to the nature of the coals. The following figures by Mr. Charles Hunt, M.I.C.E., show the proportion of ammonia removed by scrubbers working in pairs, as just described.

NH_3 removed by condensation .	. 42.7 per cent.
" " first scrubber .	. 43.3 "
" " second " .	. 14.0 "
	100.00

According to Mr. Newbigging, "tower scrubbers" should have an aggregate cubical volume of at least 9 feet for each 1,000 cubic feet of gas made per day of twenty-four hours, taking the maximum production as the basis of calculation.

There is another class of apparatus which is designed to fulfil the functions of both the washer and scrubber, the instruments being known as "washer-scrubbers." Most of this class of apparatus possess a strong family likeness. One of the best-known forms is that of Messrs. Kirkham, Hulett, and Chandler, and termed by them the "Standard Washer-Scrubber."

The apparatus consists of a D-shaped cast-iron tank, flat at the bottom, and semicircular at the top, divided laterally by vertical division plates into a number of separate water-tight compartments, in each of which is placed a sheaf of revolving discs. The discs, or metal sheets in each sheaf, are about seventy in number, having their surfaces indented to a depth of one-eighth of an inch, with the view of keeping each disc that distance from the next one, as well as presenting a projecting surface to the gas. The sheafs are suitably secured by bolts to two circular plates, which are fixed on a rotating shaft, the plate on the inlet side of the bundle of discs being hollow, and that on the outlet side plain. Each sheaf, or bundle, is immersed to about half its depth in one of the water-tight compartments, which are arranged each a little higher than the one preceding it, from the gas inlet to the outlet end, so that the clean water which enters the last, or gas outlet chamber, flows from chamber to chamber, until it finally overflows by a seal pipe to the liquor well.

The gas enters at the lowest or strong liquor chamber; passes through the hollow plate previously referred to, upwards in the spaces between the discs, then down outside the sheaf, and between it and the division plate of the next compartment into which it enters; then through the sheaf therein contained, and so on through the whole length of the apparatus. The shaft is kept constantly rotating, so as to present to the incoming gas a large extent of constant freshly-wetted surface. Clean water is admitted at the outlet end, and in its course through the apparatus absorbs a large amount of the impurities from the crude gas, and gradually gains in strength; the gas entering at the opposite end meets first with strong liquor, and gradually meets in the different chambers with purer liquor, until finally it comes into contact with clean water.

The iron discs have been superseded, in the more modern

form of instrument, by wooden laths, which are kept in position by being passed through slotted iron sheets, and then butting on to plain sheets, the whole being bolted together, and revolving each in its separate compartment, in the same manner as the sheafs previously described. This improvement materially reduces the weight on the driving-shaft.

Plate No. 2 shows the latest form of Kirkham's washer-scrubber, fitted with grid segments, water supply and liquor overflow, with glass bell covering hydrometer, so that the strength of liquor may be seen at a glance at any time. The segments, it will be noticed, are constructed of a number of wooden grids, formed by quarter-inch saw cuts being made, leaving two inches by one-eighth inch laths, and a transverse solid bar in the centre of each grid. The grids are of various sizes, and are placed one above the other with quarter-inch wooden washers between; a "crutch" bolt is then passed through (entering first the smallest grid) and the grids secured together, thus forming complete segments, which are placed between wrought-iron plates secured to the collar surrounding the driving-shaft, as shown.

The method of securing the segments between the plates is especially simple, the crutch of the bolt resting on one of the bolts holding the plates to the collars, and the grid at the circumference of the plates being secured firmly by three wrought-iron stays and bolts and nuts.

There are, in addition, numerous other washer-scrubbers, all of which have their special recommendations; of these the "Eclipse" of Messrs. Clapham and Laycock; the "Rotary" scrubber-washer of Messrs. Holmes, of Huddersfield; and the "Phoenix" of Messrs. George Waller and Co. may be mentioned. Of a different type is the brush-scrubber of Mr. George Anderson.

This apparatus consists of a rectangular vertical tower,

divided into separate compartments, in each of which is fitted a drum which is capable of revolving. These compartments rise one above another, and are connected together by suitable pipes fixed on the outside case. The circumference of each drum is fitted with a brush of whalebone, which exactly fits the compartment, which is partially filled with water, or liquor, so as to keep the brush well wetted. The gas entering at the bottom of the apparatus passes through the revolving brushes, and by way of the connecting pipes into the next higher compartment.

A stream of clean water enters the top compartment at the rate of about twelve gallons per ton of coal carbonized, and flows successively through each compartment by the same pipes as convey the gas upward, which it meets on its course, abstracting its impurities on its way, until it finally passes through the combined tar extractor and washer at the bottom.

Walker's Patent Purifying Machine is also employed for the elimination of NH_3 , together with SH_2 and CO_2 , and does its work remarkably well. The machine consists of a rectangular cast-iron vessel, containing in the lower part one of Walker's combined tar extractors and washers as previously described, and above this six superposed chambers, in which (attached to vertical shafts) are movable "devices" (boxes containing the boards for purifying the gas from ammonia). On the top of the machine is fixed the gearing which actuates a rocking beam, or beams, for working the vertical shafts holding the device boxes. The gearing and beams are driven by a small engine, placed on the ground near the machine. The gas is first admitted into the lower, or washing chamber, where it is relieved of its tarry particles, which fall to the bottom of the chamber, and are there drawn off; at the same time the gas, owing to its being divided into so many minute streams by reason of its passage through

the perforations in the troughs, is brought into intimate contact with the strong caustic liquor descending from the upper chambers when the CO_2 unites with the ammonia, forming carbonate of ammonia, relieving the gas of a large quantity of this impurity. The gas, after leaving the washing chamber, ascends through rectangular openings (over which are fixed the devices, as they are termed, containing the wetted boards) into the next chamber above, and then from chamber to chamber, having to pass between the wetted boards in each tier, until it arrives at the top of the machine freed from all traces of ammonia, and a great portion of the CO_2 and SH_2 . The frames containing the devices and boards are attached on each tier to the vertical shafts, which are themselves actuated by the dipping beams on the top of the machine, and by this means are frequently immersed in the gas liquor, or clean water, contained in each tier of the machine. Clean water is admitted into the top of the machine at the rate of ten gallons per ton of coal carbonized.

Whatever form of apparatus is employed for the abstraction of ammonia, it should always be arranged that the gas comes first into contact with strong ammoniacal liquor, and finally with clean water, so as to take out the last traces of that impurity. The outlet where the clean gas issues should be provided with a stand-pipe having a test-cock attached, and the gas should be constantly tested, either with a turmeric or reddened litmus paper, and no more water should be used than is absolutely necessary to keep the gas quite free from ammonia.

CHAPTER X.

PURIFICATION.

(Elimination.)

ON leaving the scrubbers the gas enters the vessels known as the purifiers, where the remainder of the carbonic acid and sulphuretted hydrogen are taken out, and, in modern works, a certain proportion of the so-called "sulphur compounds."

The gas at the outlet of the scrubbers should be quite free from ammonia; the approximate composition of the gas after its passage through the last-mentioned vessels being as follows:

	Per cent. by volume.
Hydrogen	48.55
Methane	39.70
Illuminants	3.30
Carbon dioxide	2.50
Carbon monoxide	2.00
Oxygen	0.45
Nitrogen	3.50
	100.00

With gas made from Newcastle coal, in addition to the above, there would also be present in each 100 cubic feet of gas, about 400 grains of sulphuretted hydrogen, and from 35 to 40 grains of sulphur as sulphur compounds other than sulphuretted hydrogen.

The reason for removing the carbonic acid is on account of its injurious action on the illuminating power of the gas, as one per cent. of CO_2 reduces the illuminating power by about four per cent.; it therefore resolves itself into a question of cost, as to which is the cheaper, to remove the CO_2 by means of lime, or to retain it in the gas and keep up the illuminating power by means of cannel, or other enriching material; but in the event of the sulphur compounds having to be removed, it is then absolutely necessary that the CO_2 should be eliminated.

In the case of sulphuretted hydrogen, however, there can be no choice, every trace of this impurity must be removed, or the gas is unfit for consumption. The London Gas Referees are so strict on this point that if a lead paper, on which gas has been impinging for a period of twenty hours, shows the slightest discoloration, "it is to be held conclusive as to the presence of sulphuretted hydrogen in the gas."

The materials employed in purification are either lime, oxide of iron, or a combination of the two; while recently a new material for effecting purification has been introduced, viz., Weldon mud.

The purifiers (fig. 28) are square, or rectangular, vessels, built up of cast-iron plates, and vary in size according to the quantity of gas to be passed through them. The plates which form the bottom and sides of the vessel should not be larger than 5 feet square, larger-sized plates being difficult to cast so as to be perfectly flat and true; the plates are provided with flanges on the edges where the joint of the plate occurs, such flanges being made of a width of 3 inches, plus the thickness of the plate, and provided with holes for the bolts which unite the plates together to pass through. The thickness of the plates varies with the size of the vessel, ranging from about three-eighths of an inch for small purifiers to three-quarters of an inch for

vessels of very large size. The flanges are made about one-eighth of an inch thicker than the plates themselves, and are cast with strengthening fillets, placed midway between each bolt hole, in order to strengthen or stiffen the flange. The faces of the flanges should be planed, or machine-faced, so that, when the plates are being joined together, all that is required is to paint the faces over with some red lead paint, and insert the necessary bolts, in order to insure a thoroughly tight joint. Purifiers are open at the top, but

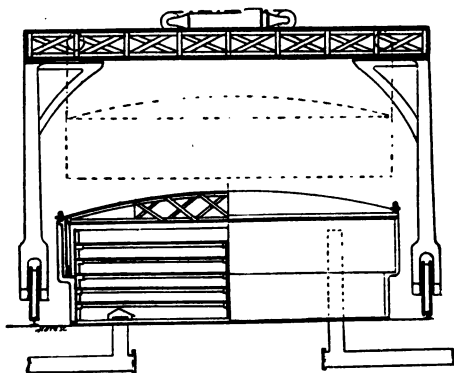


FIG. 28.

running all round the upper part of the side plate is a water lute, into which the wrought-iron cover of the purifier is placed, the sides of the latter corresponding to the full depth of the water lute, in this way forming a seal. "The water lute should be of such a depth as to offer a resistance to the passage of the gas fully equal to the combined resistance of the apparatus through which the gas has to pass;" or, in other words, the depth of the lute should be in excess of any pressure which is likely to be met with; consequently, in large purifiers the lutes are

made from 20 to 40 inches deep. The covers for the purifiers are constructed of wrought iron and are made up of a T or H-iron bottom curb and an L-iron top curb, to which are riveted side plates, which in small covers should not be less than three-sixteenths of an inch thick, increasing to, say, five-sixteenths of an inch in those of a larger size.

The roof of the cover is constructed of sheet iron of, say, No. 12 B.W.G., riveted together, and as the covers increase in size it is necessary to support the roof or crown sheets by means of curved T-iron rafters which are attached to the L-iron curb; and in purifiers of a very large size it is necessary to truss these rafters. When the purifier is duly charged with material the cover is placed over it, so that the sides rest upon the bottom of the water lute. It will then require holding down, otherwise the pressure of the incoming gas would cause it to rise out of the lute, with the consequent escape of gas. There are various methods of securing the covers of purifiers; but whatever form of fastening is adopted, they should be strong enough to withstand a strain equal to the weight of a column of water equal to the maximum pressure likely to be met with, spread over the whole area of the cover, *minus* the weight of the cover itself, the strain upon which is equivalent to the total weight of such column of water.

The material employed is placed in layers of varying thickness on wooden sieves, which rest on T-iron bearers, which fit into snugs cast on the sides of the purifiers, and on cast-iron standards fixed at certain intervals. Each purifier should be provided with one or more air-valves, fixed on the top of its cover, for the purpose of admitting air when the cover is lifted, and of allowing the same to escape when the cover is being lowered.

Provision must be made for raising and lowering the purifier covers. There are numerous means employed for

effecting this operation, one of the most common contrivances being shown in the figure.

The gas enters the purifier at the bottom of the vessel, and, after passing through the material contained therein, leaves it by a pipe at the top.

For the purpose of effecting continuous purification the vessels are worked in series, by a suitable arrangement of valves and connections, according to the requirements as to purity. In some works the only impurity dealt with in the purifiers is sulphuretted hydrogen, which is always necessary to be got rid of; in others sulphuretted hydrogen and carbonic acid are both eliminated, as the CO_2 , as before stated, is prejudicial to the illuminating power of the gas, while in modern works the sulphur compounds are also taken out.

Oxide of iron takes out sulphuretted hydrogen only, while lime takes out sulphuretted hydrogen, carbonic acid, and the sulphur compounds.

Oxide of iron has the advantage over lime, that it can be revived, and used over again for a long period, and the sulphur recovered as a marketable commodity; lime has the advantage over oxide, that it takes out, in addition to SH_2 , the CO_2 , and sulphur compounds. Formerly lime was the only purifying material employed. Lime being of an alkaline nature has an affinity for both CO_2 and SH_2 , more strongly marked in the case of the former by reason of its being the stronger acid, consequently it is the most suitable purifying material, provided it can be obtained at a cheap rate, and be readily disposed of when spent; but unfortunately these conditions are rarely met with, particularly in the neighbourhood of populous towns, therefore we find that oxide of iron is the purifying agent in most general use.

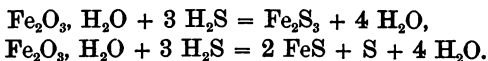
The materials named are generally employed in the following manner:

- (1) Oxide of iron alone for the elimination of SH_2 .
- (2) As above, with the addition of lime for the abstraction of CO_2 .
- (3) Lime only for the removal of SH_2 and CO_2 .
- (4) Lime and oxide for the removal of SH_2 , CO_2 , and sulphur compounds.

The methods of effecting the removal of the various impurities will now be studied in the above order.

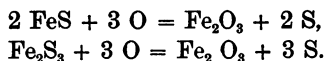
The oxide of iron used in gas-works is principally a natural product, found in the peat bogs of Ireland, known as bog ore; it is essentially a hydrated sesquioxide of iron, having the composition $\text{Fe}_2\text{O}_3, 3 \text{H}_2\text{O}$. This natural oxide usually contains 50 per cent. of water, and 32 per cent. of hydrated oxide of iron, but of this only about two-thirds is in a condition in which it can actively absorb SH_2 . It also contains about 18 per cent. of vegetable matter. As previously remarked, the ore contains about 50 per cent. of moisture, but for successful purification it should not contain more than about 25 per cent., as when the quantity is much in excess of the last-mentioned figure, it becomes less sensitive, while if too dry it gets dusty, and creeps through the grids, on which it is placed in the purifiers, and thus causes back pressure. When it is just damp enough not to pass through the grids it is in the best working condition.

The foul gas passing through the hydrated oxide combines with the latter, forming two sulphides, ferrous and ferric sulphide, water at the same time being liberated, as in the equations given below.



When the material ceases to absorb sulphuretted hydrogen, it is taken out of the purifier and exposed to the action of the air, by being placed in layers about 12

inches thick and repeatedly turned over. This operation, which is known as revivification, has the effect of causing the sulphides to deposit all their sulphur in the free state, while the iron takes up oxygen from the air, and is rapidly re-converted into oxide of iron, as in the following equation.



In the process of revivification the material gradually changes from black to its original reddish-brown colour, or, when much charged with sulphur, to a dirty green.

Oxide can be revived, in the manner just described, until the accumulation of free sulphur amounts to about 55 per cent., when it begins to interfere with the action of the oxide. It is then advisable to throw it out of action, and replace it with fresh material.

In some works the oxide is revived *in situ* by admitting a certain amount of air with the gas. This has the effect of causing the purifiers to go longer without changing, whilst the oxide can be charged with as much as 75 per cent. of free sulphur.

Owing to the heat, which is generated by the combination of the oxygen of the air with the iron sulphide, as well as to the deposition of the free sulphur, the material in the purifiers undergoes a considerable expansion in bulk; it is necessary, therefore, to make provision for the material to have free scope for expansion, by allowing a space of several inches between each layer of material.

If traces of ammonia and cyanogen find their way into the oxide purifiers, ferrocyanide of iron is formed, which greatly interferes with the action of the oxide, and prevents its subsequent revivification; but this seldom occurs when lime purifiers are used before the oxide vessels.

When put into the purifiers for the first time some

oxides are very sluggish in their action; due, in a great measure, to the high percentage of moisture which they contain. This difficulty is got over by mixing the new material with a portion of old. In using fresh oxide of iron entirely, it is necessary, as soon as a vessel has been shut out, to empty it at once, as new oxide, for the first two or three times of fouling, combines so energetically with the oxygen of the air, that the heat thus set up is sufficient to render the whole mass red-hot.

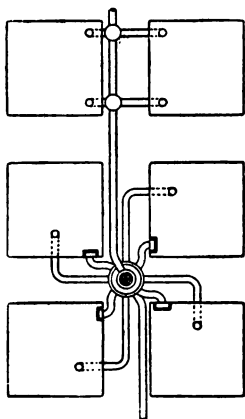


FIG. 29.

When removed from the purifiers foul oxide should not at once be spread out. "If it is allowed to remain in the heap for the space of twelve to twenty-four hours, and then distributed over the floor, the revivification is more complete, whilst the liability to ignition is reduced." This heating of the oxide sometimes makes it too dry to work properly when returned to the purifiers, so it then becomes necessary to moisten it before use.

It is further advisable to mix new oxide with sawdust, which has the effect of making the material more porous to the passage of the gas, and it also acts as an absorbent for retaining the moisture which is liberated by the reaction which takes place between the oxide and the sulphuretted hydrogen.

In purifying gas from sulphuretted hydrogen, four purifiers are frequently employed (as shown in fig. 29), three always at work and one off for changing; the various changes being made by means of a "centre valve" (fig. 30), although ordinary slide, or hydraulic valves, are

also employed. In working the purifiers in this way, when at the outlet of the second purifier a foul test is shown, the first one is shut off, and a new one put in, then what was the second purifier becomes the first, and so on; thus always insuring the third to be a clean purifier. Oxide

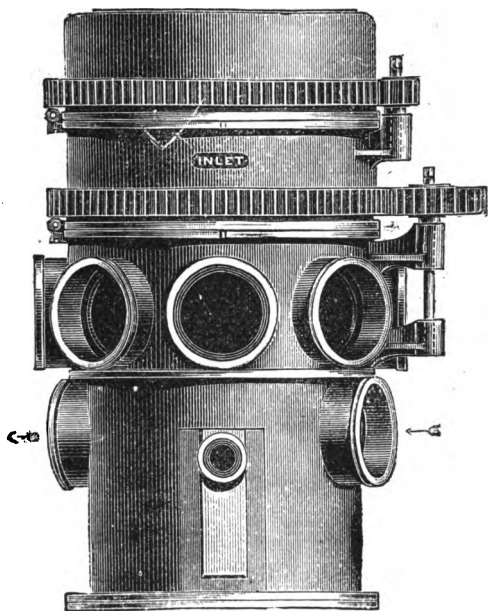


FIG. 30.

is placed in the purifiers in layers from eight to ten inches deep.

A ton of good bog ore should purify from $1\frac{1}{4}$ to $1\frac{1}{2}$ million cubic feet of gas before it becomes spent.

The chemical changes which occur when lime is used as a purifying agent will now be discussed. As previously stated, oxide of iron is only competent to deal with SH_2 ,

while lime is not only capable of removing the latter substance, but CO_2 also. Lime can also be made to remove the carbon bisulphide when used in a special way, which will be explained later on.

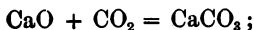
The lime used for purification is prepared in large quantities by burning chalk, or limestone, both of which are impure forms of calcic carbonate, in suitable kilns. The resulting caustic lime (CaO) is then converted into hydrate by "slaking" with water, by which its bulk is considerably increased, one yard of caustic lime yielding roughly about two yards of slaked lime. The action taking place is the union of one equivalent of lime with one of water thus:



In order that lime should be in a fit state for effective purification, it is necessary that the caustic lime should be slaked two or three days before use; as if used directly it is slaked, it is very liable to become caked in the purifiers, and thus prevent the free passage of the gas through it, which would cause an increase of back pressure. During the process of slaking, the lumps of caustic lime are converted into small powdery nodules, the bulk being a little more than doubled.

Lime, before being placed in the purifiers, should be moistened with water until it attains such a consistency that, when squeezed in the hand, it will cohere together like snow: the more water it has the better, provided it it does not run into mortar.

Lime is generally placed in the purifiers in layers of from four to six inches in thickness. When the hydrate of lime, prepared as above described, comes into contact with gas containing CO_2 free from SH_2 , the CO_2 combines with the lime to form calcium carbonate, CaCO_3 , thus:

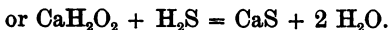
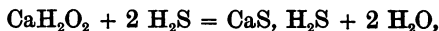


and this is what takes place when we wish to remove the CO_2 , after taking out the SH_2 , as in the second example.

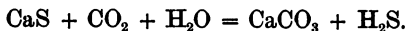
When lime is used in this way, two (or at most three) purifiers are sufficient for this purpose, placed after the oxide purifiers, as shown in fig. 29. These vessels may be placed either before or after the oxide vessels, but the latter position is to be preferred, because in the latter case the lime becomes converted into almost pure carbonate, which is without any offensive smell; otherwise, especially with only two purifiers, it is almost impossible to drive the whole of the SH_2 forward, with the result that the spent lime is very offensive.

We now come to the third case, viz., the elimination of both the SH_2 and CO_2 by means of lime.

When gas containing both CO_2 and SH_2 comes into contact with slaked lime, sulphide of calcium, and carbonate of lime are formed. The two reactions take place simultaneously, but for the sake of simplicity we will assume them to occur separately; the reaction with CO_2 has already been given, it only remains, therefore, to describe what takes place when SH_2 acts upon the lime.



It is necessary to note that lime possesses a stronger affinity for CO_2 than it does for SH_2 , and as a consequence, when a vessel has been fouled with SH_2 , and gas containing CO_2 is allowed to pass into the same vessel, the CO_2 , owing to its superior affinity for the lime, will decompose the sulphide of calcium already formed, driving off the SH_2 , and producing instead calcium carbonate, thus:



The same arrangement of vessels as when using oxide

may be employed with lime. The reactions taking place would then be as follows:—the crude gas would enter the first vessel in the series, where both CO_2 and SH_2 are removed, but a stage is arrived at when the CO_2 in the incoming gas displaces the SH_2 previously taken up, and is retained in the lime in its place; the SH_2 passes with the gas into the second vessel, where it is removed, any trace escaping being arrested in the third vessel. When the first vessel ceases to do any work, as shown by a quantitative test, it should be shut out, emptied, and re-filled with fresh material, the fourth vessel then being put into action. The vessels would then be working 2, 3, 4. At the next period of changing, when the second vessel showed a foul test, the vessels would be worked 3, 4, 1, and so on right through the series.

When, as in the present case, lime is the only material employed, there is often a risk of a little SH_2 remaining in the gas, even after traversing the three vessels. It is, therefore, advisable to use one of the two extra vessels, shown in fig. 29, as a check vessel for SH_2 , no CO_2 whatever being allowed to pass into it. This vessel should last for a considerable period if the three first vessels are properly manipulated.

It is an advantage when using lime in the manner indicated above, to admit a certain percentage of air with the gas, as it is found that the air has the effect of causing a portion of the SH_2 which otherwise would be displaced by the CO_2 , and driven off from the sulphided lime, to be deposited in the lime in the form of free sulphur.

We now come to the final case, viz., the elimination of the sulphur compounds, which depends upon the fact that carbon disulphide (CS_2), the principal of the so-called sulphur compounds, is arrested by lime which has been fouled with sulphuretted hydrogen in the absence of CO_2 , provided also that the CO_2 is kept back during the operation of its

removal. There are two principal methods employed to effect the purification of these sulphur compounds, viz., the "Beckton" system and the rotation system.

In the Beckton system eight vessels are employed, as follows :

2	filled with lime for the elimination of CO_2 ,
2	„ oxide „ SH_2 ,
2	„ lime „ CS_2 , etc.
2	„ lime, oxide of iron, or Weldon mud, as check vessels for the elimination of SH_2 .

The connections are so arranged that each pair of vessels can be worked as 1, 2, or 2, 1, and that the oxides can be bye-passed when required.

The following is the method of working this system :

Supposing the vessels to be put to work for the first time, the oxides would be bye-passed, so that the gas passes from the carbonates to the lime vessels intended for the sulphur purification; this is continued until the sulphur vessels show foul for SH_2 , when the oxide vessels are put into action. Then the two first vessels will take out the CO_2 , and some SH_2 and CS_2 , the next pair the remaining SH_2 , the next pair the bulk of the sulphur compounds, while the check vessels will take out the SH_2 which is disengaged from the sulphur vessels. By proper attention these sulphur vessels will last for a very long period; the principal point to be watched being that no CO_2 enters the sulphide vessels either when being prepared in the first instance, or when in operation, as owing to the superior affinity which CO_2 has for lime, a portion of the latter would combine with the CO_2 to form CaCO_3 , which has no action on CS_2 , and if allowed to go forward to the sulphur vessel when at work, it decomposes the combination of the lime sulphide with CS_2 , liberating CS_2 and SH_2 , which, in consequence, go forward with the gas,

in which case there would probably be found more CS_2 on the outlet than in the crude gas.

In working the carbonate vessels, supposing we were working 1, 2, as soon as No. 1 shows CO_2 , it is shut out, and No. 2 made the first vessel; as soon as No. 1 is recharged it is put in the position of second vessel: in this way there is always a clean carbonate vessel in front of the sulphur vessel.

Newcastle coal generally contains about 45 grains of sulphur other than SH_2 per 100 cubic feet, and of this quantity about 10 grains will be removed by the CO_2 vessels; and, if the vessels are in a proper condition, the sulphur vessels should take out about 25 grains more, leaving about 10 grains remaining in the gas.

In working by this method, the area of each vessel should be more considered than the total area of all the vessels, for as the gas travels through the eight vessels in succession, if the area of each vessel is relatively small, then there is an accumulation of pressure. According to Mr. L. T. Wright, an area 0.4 foot per 1,000 feet of gas for each vessel is sufficient.

The Beckton system is based on scientific lines, as each pair of vessels has a specific duty to perform, and good results can be obtained very economically.

In the rotation system, for removing the sulphur compounds, there are four purifiers of as large an area as possible, charged with lime, the gas passing through the whole series in rotation. In addition a certain percentage of air (about $1\frac{1}{2}$ per cent.) is admitted with the gas, and this has an important bearing on the results obtained. Mr. Valon, of Ramsgate, employs oxygen in place of air.

The reactions taking place are as follows:—the foul gas enters the first vessel and converts the lime contained therein into carbonate and sulphide. The next action

which occurs is the decomposition of the sulphide of calcium by the CO_2 present in the foul gas, CaCO_3 being formed and SH_2 expelled. This SH_2 , together with that present in the original gas, and which is passing unabsorbed by No. 1, pass together into purifier No. 2, whose contents become, consequently, converted entirely into sulphide of calcium, and are thus in a suitable condition for taking up the bisulphide of carbon. When the contents of No. 1 have, in course of time, become completely converted into carbonate, the carbonic acid in the entering gas begins to act on the sulphide of calcium in No. 2 vessel, converting it into calcium carbonate, and driving forward the SH_2 into No. 3 vessel, the contents of which become, in their turn, changed into sulphide of calcium, and the same thing goes on right through the series. As soon as the CO_2 shows half-way in the second vessel, then vessel No. 1 should be shut out, and when re-charged should be made the last in the series. It is necessary to have two check vessels on the outlet of the series of four, for the purpose of arresting traces of SH_2 , which may escape; these checks can be filled with oxide of iron, lime, or Weldon mud. The last-mentioned material, it may be mentioned, has lately come into vogue as a purifying material for SH_2 , for which it is extremely well adapted. Weldon mud is the result of the treatment of chloride of manganese, made as a bye-product in the manufacture of bleaching powder with lime and air by the Weldon process; the essential constituents are the hydrated oxides of manganese (MnO_2 and MnO). The reaction occurring when SH_2 is passed into it is similar to that with oxide of iron, sulphide of manganese and water being formed; in the same manner, when exposed to the air, oxidation takes place and free sulphur is deposited. The great advantage of using Weldon mud lies in its great affinity for SH_2 , which is from four to five times as great as that of bog ore.

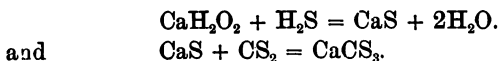
In order to work the rotation system successfully, it is necessary, when employing four vessels, to have the SH_2 in advance of the CO_2 , that is, supposing CO_2 was passing through the first and second vessels, SH_2 should at the same time be passing through the third; but if the CO_2 and SH_2 run abreast, the system fails. The vessels must be sulphided before the CO_2 passes.

In working by this system one yard of unslaked lime will purify the gas produced from, say, thirty to forty tons of coal.

The air used in this system of purification is usually drawn in at the inlet of the exhauster, but Mr. Carpenter, of Vauxhall, instead of admitting air in the usual way, introduces it into the fourth or third purifier in a rotation set. By the adoption of this plan, Mr. Carpenter claims that no oxidizing action takes place antecedent (either in the first purifiers, or earlier), to the point where the full effect of it is wanted, namely, in the purifier active for sulphur compounds; and he found that by using the air in this manner, one per cent. was sufficient to bring about regularly and reliably the desired reactions with scrubber gas containing between 40 and 50 grains of sulphur compound per 100 cubic feet.

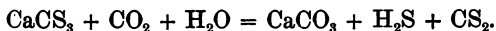
Although the sulphur compounds can be eliminated with a certain amount of success by means of either of the two methods described, the chemical reactions taking place are by no means fully understood.

It was formerly supposed that the following represented what took place:

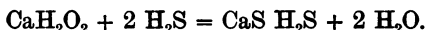


that is, slaked lime and sulphuretted hydrogen yielded calcium sulphide and water, and this calcium sulphide, on coming into contact with carbon bisulphide, produced

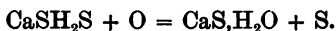
calcium sulphocarbonate; the action of CO_2 on the sulphocarbonate being



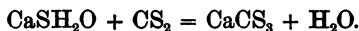
Another theory which has been propounded is, that when gas free from CO_2 comes into contact with slaked lime, a compound known as calcium hydrosulphide is first formed, as under:



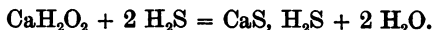
and this has no action on the sulphur compounds, but owing to the accidental admission of small quantities of air, which are always drawn in with the gas, a portion of the hydrosulphide is oxidized to hydroxy-hydrosulphide as under:



and this is capable of arresting the sulphur compounds, which it does according to the following equation:



Mr. H. Leicester Greville has suggested that the following are the probable reactions which occur, more especially where air is purposely admitted, as in the rotation system. He suggests that the particular compound which is active for taking out CS_2 is calcium pentasulphide, CaS_5 , which is thus produced:



that is, sulphuretted hydrogen and slaked lime produce calcium sulphhydrate and water, then on adding air, or oxygen, the following reaction might occur:

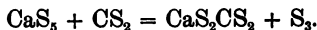


in which five molecules of calcium sulphhydrate become

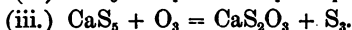
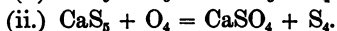
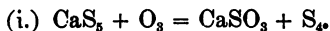
converted into two molecules of calcium pentasulphide and three of calcium hydrate.

The fact of the spent lime containing free sulphur might be accounted for in three ways.

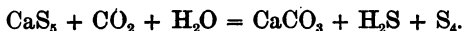
(1) As a reaction between CS_2 and CaS :



(2) As a product of the continual action of oxygen on CaS_5 , in which by equation (i.), or (ii.), or (iii.), CaSO_3 , CaSO_4 or CaS_2O_3 might be formed thus:



(3) As a product of the reaction between CaS_5 and CO_2 :



The great secret of success in all systems of purification, is to have ample area in order that the gas may pass slowly through the material; if this is not attended to, the purifying material ceases to absorb before it is spent, and there is an increase of back pressure.

There are various opinions as to the purifying area requisite for efficient working, but a very reliable one is that given by Mr. Newbigging in his excellent "Handbook for Gas Engineers and Managers," p. 143, which is: "Where there is intended to be four purifiers, three always in action, the maximum daily (twenty-four hours) make of gas expressed in thousands, multiplied by the constant 0.6, will give the superficial area in feet of each purifier."

Gas, by passing through the purifiers loses about three per cent. by volume in the proportion (roughly) of about three-quarters CO_2 and the remaining quarter SH_2 .

CHAPTER XI.

THE SIMPLEST METHODS OF ASCERTAINING THE PURITY AND ILLUMINATING POWER OF GAS.

THE simplest method of ascertaining the purity of gas is to subject it to certain *qualitative* tests, which will prove the presence or absence of the impurities, ammonia (NH_3); sulphuretted hydrogen (SH_2), and carbonic acid (CO_2).

Ammonia is detected by means of a moistened turmeric paper, or reddened litmus paper. Turmeric papers are prepared by adding to one part by weight of turmeric powder, contained in a stoppered bottle, six parts by weight of methylated spirit; the contents of the bottle should stand for about three days, and be well shaken up occasionally during the interval. Some of the clear liquid is then poured out into a photographer's dish, and sheets of filtering or botanical paper soaked therein. These sheets are then hung on lines to dry, cut into strips about two inches long and half an inch wide, and kept for use in a receptacle where they will not be exposed to the action of the light. Ammonia is detected by exposing one of these moistened papers to a stream of gas. If the gas contains this impurity, the colour of the paper will change to a brownish tint, and if much NH_3 be present, to a deep red colour. The presence of so small a quantity as about one grain of ammonia in 100 cubic feet of gas will cause a change in the colour of the test paper. The papers should

be of a full yellow colour, but not so decided as to approach an orange tint, which would render them less sensitive.

Ammonia may also be detected by means of a reddened litmus paper, which turns blue in the presence of ammonia.

Reddened litmus papers are prepared from blue litmus in the following manner:—In a stoppered bottle place half an ounce of powdered litmus, and to this add three ounces of cold distilled water, the whole should be well shaken, and then left, so that the litmus may dissolve. The extracted litmus is then filtered off, and to it is added, drop by drop, a dilute solution of sulphuric acid, until a distinct red tint appears. Strips of glazed paper are then drawn through the solution, and hung up to dry in a room free from acid fumes. Ordinary glazed paper produces a more sensitive test paper than filter paper does.

Sulphuretted hydrogen is detected by means of a paper coated with acetate of lead or nitrate of silver.

Test papers of this description are made by moistening sheets of filter paper with a solution of one part of sugar of lead in eight or nine parts of water, and holding each sheet, while still damp, over the surface of a strong solution of ammonia for a few moments. As the paper dries, all free ammonia escapes. Such papers on being exposed to a stream of gas containing sulphuretted hydrogen, turn a brownish-black tint, owing to the formation of sulphide of lead.

Carbonic acid is detected by means of a solution of lime or baryta water, generally the former.

Lime water is prepared by placing about four ounces of caustic lime into a bottle containing a quart of water, allowing it time to dissolve, and shaking it occasionally during this operation. The lime is then allowed to settle, and the clear liquid transferred to another bottle, which should be kept securely corked, so as to prevent the access of CO_2 . In order to make a test, about an ounce of the

solution is placed in a test tube, and the gas caused to bubble through it by means of a fine glass tube connected to the gas supply by a piece of indiarubber tubing. Should there be any CO_2 present, this would combine with the lime in the lime water to form a white precipitate of calcium carbonate, thus: $\text{CaO} + \text{CO}_2 = \text{CaCO}_3$. If no precipitate forms during a period of three minutes, we may assume that the gas is free from CO_2 .

It is necessary to note when testing for CO_2 in the presence of SH_2 , that the latter impurity must be removed before the gas enters the lime water, otherwise the results will be misleading. The SH_2 may be kept back by means of a small oxide purifier.

The simplest method of ascertaining the illuminating power of gas is by means of an instrument known as the "Jet Photometer."

The jet photometer is really a specific gravity test, and is based on the fact that the length of a gas jet issuing from an orifice of a certain size, under exactly uniform pressure, varies according to the illuminating power of the gas, the richer the gas the longer will be the flame; or if the length of flame be kept constant, the richer the gas, the less will be the pressure required to give this length of flame.

The instrument consists of a delicate King's gauge, surmounted by a steatite jet having a fine orifice.

In front of, and behind, this jet are glass plates, graduated upwards from the level of the burner top into inches and tenths of an inch. The photometer is inclosed in a glazed wooden case, provided at the top with a glass chimney. On one side of the case two dry governors are fixed, through both of which the gas passes, the second one being weighted to give a less pressure than the first.

From the outlet of the second governor, the gas passes through a pipe provided with a regulating cock to the

King's gauge. The gas pressure, by means of these appliances, is readily adjusted, and regularly maintained. On the opposite side of the instrument a water cistern is fixed, and by a suitable contrivance water may be admitted into or withdrawn from the King's gauge.

A jet photometer, as described above, is shown in fig. 31, and supposing that the instrument has to be put to work for the first time, the following are the instructions to be observed:¹

"Set the instrument on a firm and level base or support; carefully remove the float and the packing paper from the cylinder. Replace the float in the cylinder so that its cord lies in the front groove of the wheel above it. Pass the cord of the weight round the back groove of the wheel, and let the weight hang in opposition to the float. Take care not to strain the cords. Attach a gas supply pipe to the inlet of the governor. Pour water gently into the cylinder until the pointer exactly reaches the zero of the pressure scale. If too much water be put in, draw off the necessary quantity from the side cock. Turn on the gas, ignite it at the jet, and apply a sufficient number of shot, or of pieces of metal, to the second diaphragm of the double governor to cause the gauge to indicate, say, eight or nine-tenths pressure. Put the glass scales in their position, behind and before the burner, and make any further reduction which may be needed in pressure by the aid of the cock, or valve, at the side of the instrument. Readjust the water-level once a day."

In order to get some idea as to the value of the flame length when compared with the actual illuminating power, it is necessary to "rate" the instrument, that is, to determine the length of flame corresponding to a certain quality of gas under a certain pressure, or keeping the flame

¹ Hartley's "Gas Analysts' Manual."

length fixed at, say, 7 inches, to observe the pressure which is required to give this length of flame, and the corresponding illuminating power.

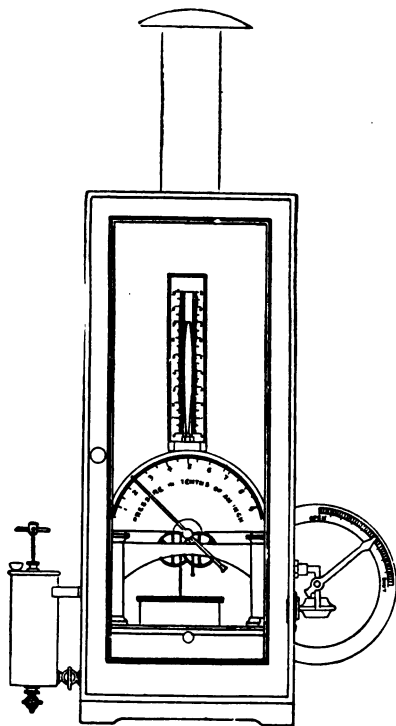


FIG. 31.

In order to rate the instrument, it is connected to the same service pipe from which the gas is supplied to a Bunsen photometer. Ten observations are made with the latter instrument; and, as nearly simultaneously as possible with each of the ten observations, the length of the flame

of the jet, or the pressure required to give a certain length of flame is noted. The mean of the lengths of the jet, or the pressure required to give a certain length are then taken and recorded. The illuminating power as determined by the Bunsen photometer is also recorded. The experiment is then repeated with a second pair of candles if that standard is employed.

Comparative experiments made in the above manner are continued over a sufficiently long period, and with varying qualities of gas, until a comprehensive table is obtained. The most suitable position for fixing the jet photometer is on the outlet of the exhauster, as, when fixed in that position, a continuous record is obtained of the quality of the gas as it comes from the retort-house, hence any falling off in the quality of the gas can be at once detected and remedied; it is necessary to take out the impurities SH_2 and CO_2 , before the gas enters the instrument, by passing it through two small purifiers filled with oxide of iron and lime respectively.

CHAPTER XII.

A DESCRIPTION OF THE VARIOUS INSTRUMENTS USED IN GAS-WORKS FOR ASCERTAINING AND RECORDING PRESSURE AND EXHAUST.

IN the conduct of a gas-works it is very essential to be able to know at any moment the "pressure" or the "exhaust," as the case may be, at any particular portion of the gas-making plant, and this information is obtained by means of the instrument known as a "pressure gauge," which, although of very simple construction, is an exceedingly valuable instrument, as it acts as a sentinel by which we are enabled to tell if there is a clear course for the gas, any obstruction or stoppage being shown by an increase in the pressure.

The pressure gauge in its simplest form consists of a glass tube of about five-eighths of an inch internal diameter, bent in the form of the letter U. The tube is provided with a scale, divided into inches and tenths of an inch, which is placed between the two limbs of the U. The zero point of this scale is in the centre, and the divisions are marked above and below the zero mark. The tube is filled with coloured water to the level of the zero mark.

One of the ends of the tube is provided with a brass cap, pierced with a small hole, so that the pressure of the atmosphere is capable of pressing on the liquid contained in that limb, while the other limb is provided with a suitable attachment for connecting to any apparatus, the pressure

of gas in which we require to know. On allowing the gas to enter the gauge, the pressure of the same will depress the water in the limb to which it is connected, and raise it to the same extent in the opposite limb, the distance between the two levels indicating the amount of pressure. The amount of pressure up to two or three inches is generally spoken of as being so many tenths; when greater than this the term inches is applied. Fig. 32 shows one form of pressure gauge.

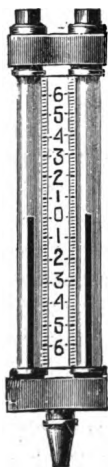


FIG. 32.

Sometimes in place of having one limb open to the atmosphere and the other to the gas supply, one limb is connected to the inlet of an apparatus and the other limb to the outlet of the same apparatus; in this case the difference in level shows the pressure thrown by the apparatus, for should the apparatus not be throwing any pressure, the gauge would not show any difference in level, as the two pressures would balance one another; but as the inlet pressure is always the greater, we always find in practice that there is a difference, and, consequently, we find a difference in the level of the gauge. For instance, if we attached such an instrument to the inlet and outlet of, say, a scrubber which is showing 30 inches pressure on the inlet, and 29 inches on the outlet side, the pressure gauge thus connected would show a pressure of 1 inch which would be the amount of pressure thrown by the vessel. As in many cases we simply wish to know the pressure thrown by a particular vessel, this form of gauge, which is known as a "differential pressure gauge," is extremely useful, particularly when fitted with a special arrangement of cocks, by means of which either limb of the gauge can be put into communication with the atmosphere, or gas supply at will; by this arrange-

ment we obtain, in addition, the actual amount of pressure as with an ordinary gauge.

When the pressure gauge is connected to the inlet side of the "exhauster" as, say, in the retort-house, the difference in level between the two limbs of the gauge then indicates "vacuum" or exhaust.

Thomas's pressure gauge consists of two tubes of different diameters, placed concentric to each other, the gas entering the smaller tube. In this form of gauge the height to which the column of liquid is depressed and elevated is not the same in both tubes, but is in inverse ratio to their respective sectional areas.

In cases where we wish to ascertain the amount of pressure very exactly, as for example, when using the jet photometer, or making an ordinary photometrical test, an instrument known as King's gauge, is employed. This consists of a water-chest divided into two chambers, one of which, into which gas is admitted, being closed to the atmosphere, while the other chamber, which is in communication at the bottom with the closed chamber, is open at the top to the atmosphere. When gas is allowed to enter, the water in the closed chamber is depressed by the pressure of the gas, and elevated in the open chamber. A metal float rests on the surface of the water and is connected to a pulley wheel by a cord provided with a counterbalance weight. On the pulley spindle a pointer is fixed which traverses over a semicircular scale graduated to hundredths of an inch. The action of the instrument is exceedingly simple, as the water in the open chamber rises and falls according to the pressure of gas acting on the water in the closed or gas chamber; the float also rises and falls, and its movements are transmitted to the pointer, which indicates on the scale behind it the pressure exerted by the gas.

Pressure gauges, however, only indicate the pressure to which they are subjected at any particular moment; so in

cases where it is necessary to have a continuous record during any particular period, say for twenty-four hours, it is necessary to employ the instrument known as the pressure or exhaust "register."

This instrument (fig. 33) consists of a tinned plate tank about 3 feet deep and 16 inches diameter, in the centre of which rises a vertical pipe attached to the gas supply. On the top of the tank there is a receptacle for a vertical revolving cylinder, about 16 inches long and 5 inches diameter, which is enclosed in a glass case.

The cylinder is connected to a clock which is placed on the top of the apparatus, and which causes the cylinder to revolve once in twenty-four hours.

Within the tank a gas-holder of about 14 inches diameter and 16 inches high is placed; this holder has a float throughout its length, which gives it the required degree of buoyancy when immersed, but causes a gradually increasing weight, and consequently pressure, on rising.

The holder is provided with rollers, working in guides, so that it may rise and fall with freedom.

Attached to the top of the holder is a rod, which passes through the centre of the cover of the tank, and on the top of this rod a spring pencil is fixed, for the purpose of recording the variations in pressure.

A sheet of paper is coiled round the vertical cylinder, and this paper is divided off into twenty-four vertical divisions, which indicate the hours of "day" and "night" corresponding with the clock fixed above. On the same paper there are a series of horizontal lines corresponding with the pressure; these horizontal lines are also numbered, commencing from the bottom, which is the zero point, and indicating tenths, continued to forty or fifty tenths. As the holder in rising, by reason of its having less buoyancy, gets gradually heavier, on ascertaining this

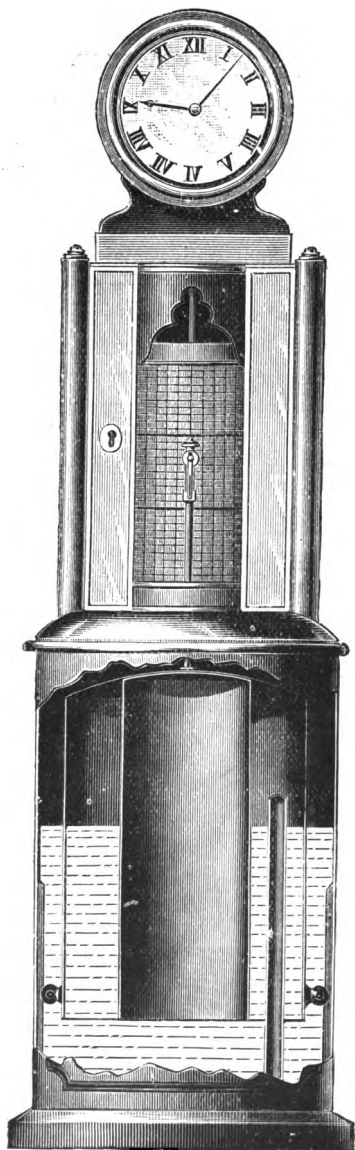


FIG. 33.

weight at various positions, the scale of pressure can be arranged accordingly by the horizontal lines.

The action of the instrument is as follows:—On the tank being supplied with water to the desired height, if there be no pressure, the holder will of course remain stationary, and the pencil will remain at zero; but supposing we admit gas, say at a pressure equal to 1 inch, the holder will rise, carrying with it the pencil which records the pressure on the horizontal lines of the coil of paper, while at the same time the vertical lines indicate the time at which that particular pressure was given.

The difference between a “pressure” and “exhaust” register is simply one of detail in their construction. The zero line of the “pressure” register is at the bottom of the scale, while in the “exhaust” register it is placed midway on the scale, which necessitates the spindle being made longer, the area of the float being also increased.

A pressure register should be placed in communication with the street mains after the gas has passed through the governor. When employed to register “exhaust” it should be connected to the “exhaust” or inlet side of the exhauster.

CHAPTER XIII.

THE GAS-HOLDER AND ITS TANK.

THE scope of this little work will not permit of any extended account of the construction of gas-holders and tanks, which calls for the exercise of the highest engineering skill; all that will be attempted is to give a brief sketch of the general features of such constructions, referring the student for fuller details to King's "Treatise," Cripps, "The Guide Framing of Gas-holders," Newbigging's "Handbook," and the technical journals.

The tank of a gas-holder is a circular reservoir of water, slightly larger in diameter than the gas-holder itself, and in this reservoir the gas-holder works, rising or falling above or below the water as the gas is stored or taken away for distribution.

Tanks are generally built under the ground level, but in some instances, where it is requisite, owing to special circumstances, to construct them of iron, they are placed entirely above ground. Tanks are sometimes "formed by making a circular cutting in the ground, and erecting therein an iron or brick annular channel to contain the water, the intervening or central space being also covered with water, but only to a few inches depth. These are called annular tanks."

Tanks are constructed of brick, stone, or concrete, according to circumstances, the material employed largely depending upon the materials most cheaply obtainable in

the locality, and the nature of the ground in which it is proposed to construct the tank, which in some instances necessitates the employment of tanks constructed of cast or wrought-iron plates bolted or riveted together, "but such tanks are only employed under very special circumstances, as their cost is much greater than either brick or stone."

Tanks other than those made of iron are generally sunk level with the ground, or to within a few feet of the surface, the portion of the walls which is above ground being strengthened by an earthen backing. They are made water-tight by being surrounded on the outside with clay puddle of from 12 to 24 inches in thickness, or as a substitute for this, the tank is rendered on the inside with cement.

"In a brick and puddle tank the pressure due to the water it contains is transmitted through the porous brickwork to the clay puddle and earth backing, which are slightly elastic. When, however, cement rendering is employed, the tank walls have to sustain the bursting pressure of the water; and their stability largely depends upon the selection of the material to form the earth backing, and the care with which this is filled in, rammed, and watered" (Hunt).

Before adopting any particular site for the construction of a tank, it is necessary to sink a well or shaft in the vicinity, or to make a number of trial borings in close proximity to the site, in order to ascertain the nature of the strata in which the excavation for the proposed tank has to be made. If any considerable quantity of water is found, it will then be necessary to make provision for its continuous removal during the progress of the work in the following manner.¹

¹ Newbigging, "Trans. Incorporated Gas Institute, 1892."

“The first thing to be done is to sink a well or sump, 3 feet to 4 feet in diameter, at a convenient distance from the circumference of the proposed excavation. This should be lined with open, unmortared brickwork (technically called steining), to allow of the free percolation of the water into the well or sump through the joints of the lining.

“Into this, when the sinker has reached the water-bearing strata, he conveys the suction-pipe of the pump, puts the latter in operation, and clears out the inflowing water, to enable him to proceed with his work. This well is carried down to a depth of 3 feet to 5 feet (depending on the volume of water present) below the bottom of the intended excavation, and is then paved with bricks set in cement. If the strata are of uniformly open character, consisting, say, of a mixture of gravel and sand, one sump will be sufficient to clear the ground of water; otherwise, if it is not uniform, but barred by intervening clayey deposit (not an unusual thing), and even by solid-bedded sand, for this sometimes is almost as impervious as clay, it may be necessary to drain the water to the sump, or even to put down two or more sumps outside the ground operated on. Duplicate pumps should be provided where the flow of water is very great. With these arrangements completed, the work of excavating and building can be proceeded with, unhindered by the presence of any undue amount of water.”

When employing puddle in the construction of a tank, after the necessary excavation has been made, which is to be well shored up and strutted, a layer of puddle, 2 feet thick, prepared from good stiff clay by well soaking it with water, cutting it up, and turning it over until it becomes a soft, homogeneous mass, is first put all over the bottom and under the brickwork footings, and a portion of the circular wall of the tank is raised, say, 3 feet high. Puddle is then thrown in between the excavation and the

brickwork, and this is continued until the necessary height is obtained. In order to save expense, both in labour and water, it is usual to leave a portion of the centre of the tank untouched. This unexcavated portion is known as the "dumpling," and it is also necessary to puddle up the sides, and over the top of this dumpling, so as to make the tank water-tight. The dumpling serves to support the king post of a trussed gas-holder; or, if the holder is of the untrussed type, the timber framing which supports the roof when the holder is down.

During the progress of the work it is necessary to see that the circle required is adhered to, this is insured by the use of the contrivance known as a "trammel;" and, also, that in the building of the wall, the latter shall rise to the same height all round the tank, as if some portions are higher than others, then there would be a risk of unequal settlement, which would probably result in a fracture.

On the bottom of the floor of the tank "rest stones" are bedded, for the purpose of "resting" the bottom curb of the holder when the latter is empty. At certain points in the tank wall stones are inserted, for the purpose of receiving the bolts which fasten the tank guide rails, and at specified intervals piers are formed which must be tied in with the rest of the work; these piers take the holding-down bolts, etc., of the gas-holder columns, and are capped at the top with a stone, which serve as the base for the columns. The holding-down bolts are fixed and built in during the construction of the tank. They are secured at their lower end by cast-iron holding-down plates, which are built into the piers.

According to the size of the tank so does the thickness of the tank wall vary, the range being, say, from four and a half to two and a half bricks at the bottom, to from two and a half to one and a half bricks at the top,

the reduction in the thickness of the wall being made by "set offs" at predetermined heights, and on the outside of the wall. The top of the tank is usually finished off with a brick or stone coping.

As previously remarked, it is necessary to sink a sump, and to keep pumps continuously at work, in order to keep down the water, until the completion of the tank, when the permanent water required in the tank is gradually filled up to the necessary level, and its weight on the puddle over the bottom and dumpling prevents the bottom from blowing, and the nuisance and expense of a leaky tank.

Concrete is now greatly used in the construction of gas-holder tanks, and in places where proper ballast is easily and cheaply obtainable, it is a most economical material if properly mixed and built up. The concrete is made of Portland cement, the proportion being about one of cement to seven of well-washed ballast, with a small proportion of clean, fine sand. The excavation for the concrete is an annular ring, rather wider than the width of the concrete sides, carried down to the necessary depth, and polled and strutted from the sides. The bottom part should be made wider than the actual wall, and left rough, so that when the interior of the tank is taken out a rugged part may present itself to combine with the new concrete forming the bottom of the tank. When the whole is completed, it is rendered over with a coating of neat Portland cement of from three-quarters to 1 inch in thickness. Of course the water has to be kept out of the work during its progress, and must be particularly watched in the construction of tanks of this description, or it will wash away the fine particles of cement from the ballast before it has time to set.

During the construction of gas-holder tanks, the inlet and outlet pipes for the circulation of the gas through the holders must be arranged for. The pipes, which vary in diameter according to the size of the holders, are usually

spigot and socket. They are carried down the outside of the tank and below the bottom, and return up the interior of the vessel; the end, or open mouths, of the pipes being some 8 or 9 inches above the level of the water. The bottom of the interior pipes fit into cast-iron bends, and are carried, with a proper amount of fall, into what is called a "bell syphon," which is arranged to take the pipes rising outside the tank, and also to form a syphon to catch any leakage of water, should there be one, or any condensed water that may be made during the travel of the gas through the pipes. These syphons require regular supervision and pumping.

Cast-iron tanks are constructed of flanged plates cast to the radial curve of the tank, the plates being usually made 4 feet 6 inches long and 3 feet 6 inches deep, provided with flanges $2\frac{1}{2}$ or 3 inches wide. The flanges are cast with holes about 6 inches apart, for the purpose of receiving the bolts which join the plates together. The thickness of the plates vary according to the size of the tank. In large tanks, say from 80 to 150 feet in diameter, the bottom plates range from an inch to an inch and a half in thickness, while the side plates vary from an inch to an inch and an eighth in thickness for the bottom tiers, reducing from five-eighths to three-quarters of an inch for the top tiers. The plates for smaller tanks are, of course, made thinner in proportion, but in all cases it is necessary to place iron bands round the outside of the tank, secured together by means of cotters, otherwise it would not be safe to trust to the tank being sound. The flanges of the bottom plates are always placed on the inside, while the side flanges are generally on the outside.

Iron tanks should be bedded on a concrete foundation, the latter being perfectly level.

The columns, or standards, for guiding the holder are generally attached to brick piers by means of holding-down

bolts built into the latter, the piers being kept separate from the holder; but in the case of tanks of a very small size the columns are carried on brackets cast on the tank, the columns being connected at the top by T-iron girders in the usual manner.

Iron tanks are made of different diameters up to 150 feet, but are rarely more than 25 feet deep.

The Gas-Holder.—The gas-holder is the vessel in which the gas made is stored, and the storage capacity of a gas-works should be equal to the maximum quantity of gas consumed in twenty-four hours.

The holder is a cylindrical vessel closed at the top, which is known as the roof, and open at the bottom; holders are made of sheet-iron of varying thickness, according to the size of the vessel. The holder is rather less in diameter, but of the same depth as the tank in which it floats, and is guided by rollers, which are attached to its upper and lower edges at intervals along its circumference, the rollers working against suitable guides fixed in the tank, and on a series of columns, or standards, placed at equal distances around the top edge of the tank, so as to allow the holder to rise and fall with freedom.

The action of the gas-holder, by which it rises and falls, is as follows:—Supposing the holder to be empty of gas, and the tank filled with water, then, on allowing gas to enter the inlet pipe, as there is a space between the surface of the water and the roof of the holder, and the top of the inlet pipe is above the level of the water in the tank, the gas fills this space, and as it possesses a certain amount of force or pressure, this pressure is exerted on the surface of the water and the underside of the roof, thus causing the holder to rise. The water in the tank may be said to serve three purposes: it offers the necessary resistance to the gas, which enables the holder to rise, and when the holder is falling it is the medium by which the gas is ex-

pelled ; it also prevents the gas from escaping from the holder.

There are two descriptions of gas-holders, the "single lift" and the "telescopic." The single-lift holder is shown in fig. 34, and simply consists of one single cylindrical vessel floating in a tank, as previously described. The single-lift gas-holder shown in the figure may be taken as a type of this class of construction, and is made up of

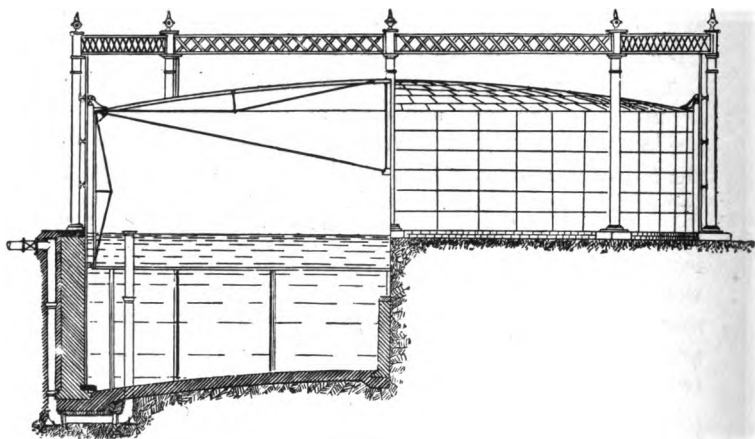


FIG. 34.

the framing and the sheeting. The framing at the top consists of an angle-iron ring, known as the top curb, upon which the roof or crown of the holder is formed. The roof is frequently supported by trussing, the trussing consisting of a series of radiating bars of T or flat bar-iron diverging at equal distances from the centre plate of the holder, which is known as the crown plate, to the top curb. The roof is sustained in the centre by a short column known as the "king post," into the bottom of which are inserted, and

held by it, a series of tension rods which radiate to the top curb; there are also suspension rods, which carry struts for sustaining the centre of the radiating bars. The roof of a holder has a certain amount of rise (about one-twentieth of the diameter) from the top curb to the crown plate. To the top curb a series of vertical stays, usually of T-iron, are fixed, distributed at equal distances round the circumference for the purpose of securing the side sheets. The bottom of the holder is known as the "bottom curb," and is frequently formed of flat bar-iron shaped to the proper curve, and placed between two angle-iron rings, to which it is securely riveted, the vertical stays being also secured to the bottom curb. The whole of the top and side framing is covered with thin sheets of plate iron, the thickness of the plates employed depending upon the size of the holder and other circumstances. It is necessary to note that it is only when the holder is empty or grounded that the roof and sides require any support, the holder when inflated having very little strain upon it, consequently the trussing is in a measure superfluous, as adding unnecessary weight to the holder; for this reason many engineers dispense with the trussing, the holder when empty being supported by a timber framework, shown in fig. 35. In untrussed holders the top curb is considerably strengthened in order to enable it to resist the additional strain to which it is subjected, and with the same object a greater rise is given to the crown.

Placed at equal distances around the holder are the guide columns, to which the vertical guides are fixed for guiding the holder up and down as it rises and falls. These were formerly made of cast-iron, but at the present day they are almost always made of wrought-iron, in the form of lattice-work standards, as wrought-iron is a much lighter and more reliable material. These standards are braced together at the top and in the centre by wrought-

iron girders, which connect one standard with another all round the holder, and fixed to the standards in a truly vertical position are the guides, which are usually of T-iron. The carriages containing the guide rollers are secured to the roof sheets of the holder close to the top curb, so as to admit of the rollers working against the guides. The carriages are constructed so as to allow of their being adjusted when required, and they are fixed in such a manner

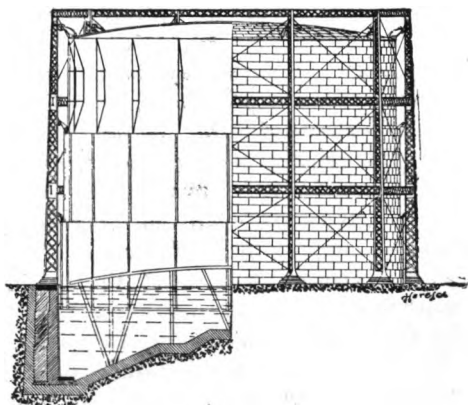


FIG. 35.

that the rollers work quite freely along the T-iron vertical guides. Corresponding carriages are also fixed on the bottom curb which carry the bottom guide rollers; these work in the vertical guides placed in the tank, the latter being usually made of channel iron.

The telescopic gas-holder is shown in fig. 35, and may be said to consist of an ordinary single-lift gas-holder, called the upper lift, surrounded by another similar cylinder of about the same height, but minus the roof. These are both immersed in the same tank.

The bottom of the upper holder or inner lift is so arranged as to form a deep annular channel all round the lift, which is shown in fig. 36. This channel, which is known as the "hydraulic cup," in rising is filled with water. The surrounding cylinder, or lower lift, is about from 12 to 18 inches larger in diameter than the inner lift, and is furnished with a similar annular cup, but inverted, called the "grip," so that when the inner holder rises to the top the inverted cup "grips" on to the water lute of the latter, so that the gas is prevented from escaping. The inner holder in rising carries with it the second lift.

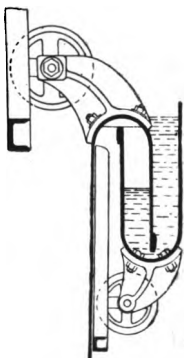


FIG. 36.

The bottom guide-roller carriages of the inner lift are fixed on the under side of the hydraulic cup, and on the under side of the outer lift suitable guides are fixed for the rollers to travel along, the guides also serving as vertical stays to the outer lift. The top guide-roller carriages of the outer lift are fixed on the hydraulic grip. These rollers answer to the rollers of an ordinary single-lift gas-holder. From the above description it will be seen that "telescopic" holders derive their name from the fact that the various lifts slide within one another, something after the style of the tubes of a telescope. Telescopic holders are sometimes made with as many as four lifts. The advantages of the telescopic over the single-lift holder are, that a telescopic holder is capable of storing nearly two or three times (according to the number of lifts) more gas in a given area, so that a considerable economy is effected by reason of the same tank sufficing for a greatly increased holder capacity.

It is necessary to give attention to the lutes of telescopic holders in frosty weather, so that any ice which may form is at once broken up, otherwise there is a risk of seriously damaging the holder.

One of the most recent developments of gas-holder construction is that of the abolition of the guide framing as being superfluous; and of the various contrivances which have been designed to act as substitutes for the guide framing, those of Mr. Gadd and Mr. Lloyd Pease are specially worthy of mention as being in practical operation.

In Mr. Gadd's system the ordinary vertical tank guides are placed at an angle of not less than 45° instead of in the ordinary vertical position.

The guides thus placed form a portion of a screw thread, and by the employment of a pair of tangential rollers, one on each side of the guide, fixed to the bottom curb, the holder on rising and falling has a screw-like motion given to it to the extent of about one quarter of a circle. The effect of arranging the guides in such a manner, with a roller on either side, is to cause the holder to lock, so to speak, and thus resist any overturning force that would be likely to be exerted upon it, whilst the gripping or locking action on the angular guides allows the rollers free scope to ascend or descend in the guides.

There are one or two calculations connected with the subject of gas-holders with which the student should make himself familiar. In order to find the cubical capacity of a gas-holder, the rule is, multiply the area of the diameter by the working depth in feet, and in order to obtain the area, we multiply the square of the diameter in feet by the constant 7854; this product multiplied by the depth gives the cubical capacity.

When calculating the capacity of a telescopic gas-holder it is necessary to take out the capacities of the several lifts

separately; an inner lift being measured from the top curb to the bottom of the cup; a middle lift being taken at its total depth minus the depth of the dip; and a bottom lift is less the dip, and the depth to which it is immersed in the tank in order to keep the seal so as to prevent the gas from blowing.

From a knowledge of the pressure thrown by a holder, and the area of the top of the vessel, we can arrive at a close approximation to its weight; and conversely, knowing the weight and area, we can estimate the pressure which a holder will give. All calculations of this character are based on the weight of a cubic foot of water, which is 62·5 lb., from which we know that a column of water exactly 1 foot square and 12 inches high is equal to $62\frac{1}{2}$ lb., or a column of the same area 3 inches high is equal to 15·625 lb., or a column 1 inch high is equal to 5·21 lb.

Consequently, if we wish to ascertain the weight of an uncounterbalanced holder, giving a certain pressure, then on multiplying the area of the top in feet by the weight corresponding to a column of water of the height of pressure given, the weight will be arrived at. In order to arrive at the pressure which will be given by a holder of a certain weight, we divide the total weight of the holder by the area in feet, this will give the weight of a square foot; from which the pressure equal to a column of water of that height is obtained.

The following formulæ shortly express the meaning of the above:

Calling W = the weight of the holder in pounds,

A = the area of the holder in feet,

P = the pressure in inches head of water,

$$P = \frac{W}{A \times 5.21} \text{ and } W = P \times A \times 5.21.$$

A single-lift gas-holder usually gives a pressure of 3 or 4 inches head of water, the amount thrown depending upon the ratio of the depth to the diameter, while each outer lift of a telescopic holder throws a pressure of about 2 inches head of water.

CHAPTER XIV.

THE PRACTICE OF PHOTOMETRY.

THE object of photometry is to measure the amount of light emitted from a luminous body, and this information is obtained by the aid of a well-known law in optics, viz., that light varies inversely as the square of the distance; i.e., that as a body is removed from any source of light, it receives less and less illumination according to the distances to which it is removed; and that if at any two distances we fix the body and square the distances, the illumination the body receives is inversely as these squares.

The above facts could be shown to be as stated by means of the following simple experiments.

“Suppose a person placed in a perfectly dark room, and a light (fig. 37) to be in another room, and a hole a foot square to be cut in the door of the dark room at 1 foot from the light, and a screen to be placed close to the hole in the door. A square 12 inches on each side would be illuminated by the light, and the rest of the screen would be dark.

“If the screen be moved a foot from the hole in the door, and therefore 2 feet from the light, the illuminated area will be a square 2 feet on each side, or 4 superficial feet. If the screen be placed 1 foot further from the door, i.e., at 2 feet distance from the hole, and 3 feet distance from the light, its illuminated area will be a square 36 inches on each side, and, therefore, containing 9

superficial feet. Similarly, if it be removed 1 foot further still, *i.e.*, 3 feet from the hole and 4 feet from the light, its illuminated area will be a square of 48 inches on the side, which will contain 16 superficial feet, and so on for every additional foot by which it is removed from the light. Now, the number of feet illuminated will be found exactly the same as the squares of the distances at which the screen is placed from the light.

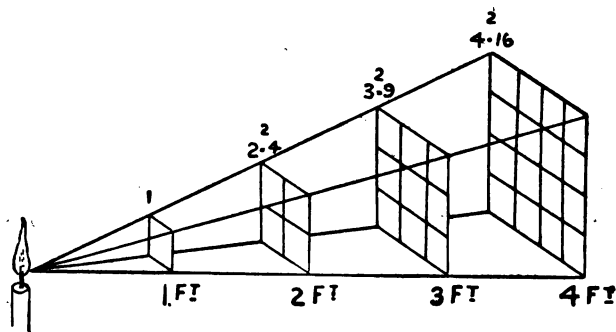


FIG. 37.

$1^2 = 1$ = portion of screen illuminated at 1 foot distance.

$2^2 = 4 =$ " " " 2 feet "

$3^2 = 9 =$ " " " 3 " "

$4^2 = 16 =$ " " " 4 " "

"So that the area illuminated is found to vary directly as the square of the distance from the light.

"But the information we require to know is how much light falls on a given unit of surface. We know that all the light which passed through the hole fell upon the screen when it was close to the door, at 1 foot distance from the light, and this is the entire quantity of light received by the screen at each of its positions. But the quantity which was concentrated upon 1 foot, at 1 foot distance, was

spread over 4 feet at 2 feet distance, and therefore the quantity upon each foot of screen must be a fourth of the entire light. Again, at 3 feet distance the light spread over 9 feet of the screen, and therefore the quantity upon each foot must be one-ninth of the whole. In the same way at 4 feet distance the light spreads over 16 feet, and, therefore; the light on each foot must be one-sixteenth of the whole, and so on for any given distance. Therefore, in order to find the amount of illumination of a given area, all that is required is to measure the distance of the illuminated body from the light, and to square that distance, and we then obtain an expression of the quantity of light received by the given area as compared with that which it would receive at a distance fixed upon as unity" (Bowditch).

The celebrated Count Rumford devised a method for the estimation of light by means of what is known as the shadow photometer, and made use of the above-mentioned law.

This method was very generally employed for several years, and in order to make the description quite clear we will explain how to use the shadow photometer for comparing the illuminating powers of a lamp and a standard sperm candle.

Place a vertical rod in front of a white screen (fig. 38). Commence by placing the candle and lamp side by side, about a foot in front of the rod. Two shadows of the rod will be then thrown on the screen, one by the candle, and one by the lamp, the latter being the darker of the two. Now what does this indicate? It must be borne in mind that there are two sources of light illuminating the screen, and that each shadow is only a *partial* shadow. The part of the screen on which the candle shadow falls receives no light from the candle, but it *does* receive light from the lamp. In the same manner the part of the screen on which the lamp shadow falls receives no light from the

lamp, but it does receive light from the candle. Since the former shadow is not so dark as the latter, and both sources of light are at the same distance, we arrive at the conclusion that the lamp emits more light than the candle. Now move the lamp farther away until the shadows appear of the same depth. In order to see this effect plainly the lamp should be placed in such a position that the two shadows are formed side by side, as in the figure. Now measure off by means of a rule, the distances from the screen to the candle, and from the screen to the lamp, and we will sup-

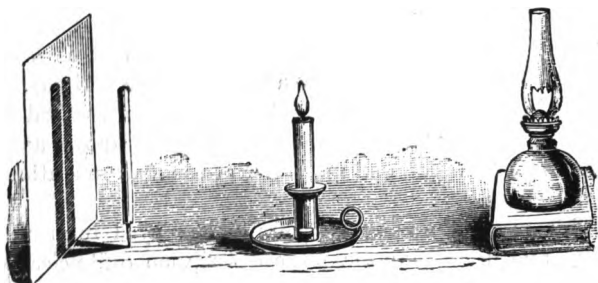


FIG. 38.

pose for the purpose of illustration that these distances are 1 foot and 2 feet respectively when the shadows are of equal depth. It will consequently follow that the illuminating power of the lamp is to that of the candle as $(2)^2$ is to 1, or as 4 is to 1.

In connection with the shadow photometer it is necessary to recollect that although the comparison is made by judging of the comparative *depths* of two shadows, what are really being compared are the intensities of illumination on two adjacent portions of the screen, and adjusting these to equality; also that the illuminating powers of the two sources of light are *directly* proportional to the squares of their distances from the screen. If the distances had

been 1 foot and 3 feet (instead of 1 foot and 2 feet), the illuminating powers would have been 1 to 9, and so on. In other words, in order to obtain the relative illuminating powers of two sources of light when tested by means of the shadow photometer, the rule is to square the distances of the two sources of light, and divide the one into the other.

For example, suppose a gas flame is fixed at 100 inches from the screen, and it is found that the shadows are equal when the candle is 25 inches from the screen, then the gas would give 16 times the light of the candle, or would be what is known as 16-candle gas, for

$$100 \text{ inches} = 25 \times 4, \text{ and } 4^2 = 16, \text{ or } 25^2 : 1 :: 100^2 : x.$$

$$\therefore 625 x = 10,000$$

$$\therefore x = \frac{10,000}{625}$$

$$= 16$$

or $100^2 = 10,000$, and $25^2 = 625$,
and $625 \overline{)10000}$ (16

625

3750

3750

The photometers employed at the present day, however, are all based on a method suggested by Bunsen. The principle consists in saturating a piece of white paper with melted spermaceti, leaving a portion in the centre untouched. Now when a piece of paper so treated is held between the observer and a source of light, the portion which has been saturated with sperm, by reason of its being more transparent than the central portion, which has not been so acted upon, will appear light, while the central or untouched portion will appear dark. If, however, the disc be illuminated from the same side as the observer, the converse effect will be produced, the central portion appear-

ing bright, and the outer or transparent portion comparatively dark. This effect arises from the fact that the most opaque portion of the disc effects the greatest amount of reflection of light, and consequently appears the brightest, while the light which falls on the more transparent portion is more transmitted and less reflected: if the disc is placed between two sources of light of the same intensity the disc will appear equally bright on each side, consequently no distinction will be apparent between the opaque and the transparent portion; but should one of the sources of light be greater than the other in relation to the position of the disc, the central portion of the latter will appear darkest on the side of the weakest light, caused by the reflection of light on the one side being less than the light transmitted from the other. The opposite side of the disc shows a contrary effect, the opaque portion in this case appearing brighter than the surrounding portion, owing to the reflection of the light being greater than its transmission. As previously stated, Professor Bunsen employed this device for the purposes of practical photometry. A piece of paper prepared as above described was placed between the two lights to be compared, and moved until it was equally illuminated on both sides, the equality of illumination being indicated by both sides of the paper appearing alike. The distance of each light from the paper was measured and squared, and the value of one light was thus obtained in terms of the other.

“As soon as the Bunsen disc came to be used for accurately measuring the illuminating value of different sources of light, various forms of photometers began to be introduced. The instrument first consisted of an open bar, 100 inches in length, with the Bunsen disc fixed on a frame, which rolled on the bar, and could be moved backwards and forwards. At one end of this the standard burner was arranged; and at the other end, the candle

which was to be used as a unit of light. This was afterwards improved by Dr. Letheby, who fitted the disc in a small box open at each end to the two sources of light, and sliding as before upon the bar. In the front of the box was an opening through which the observer looked, and across which, at right angles, came the edge of the disc. This sighting-box was fitted with two small mirrors at such an angle that the reflection of the two sides of the disc could be simultaneously seen by the observer standing in front of the box. A still greater improvement was also made by replacing the one candle-flame by two flames emitted by two halves of the same candle. The candles used for testing gas are mould candles, and are therefore slightly taper, in order to admit of their easy removal from the mould in which they are cast; and if one candle only be employed, the quantity of sperm melted during its consumption will be continuously altering. The great improvement consists in cutting the candle in half, and lighting in the middle, so that while one half burns down to the thick end, the other burns down to the thinner end. These candles are arranged upon a small balance, so that the amount of sperm consumed during the period of testing can be accurately determined; and, under existing regulations, only those candles that burn more than 114 or less than 126 grains of sperm per hour are considered to comply with the term 'standard candles.' Dr. Letheby also reduced the length of the bar from 100 to 60 inches. This may or may not be an advantage, according to the state of the atmosphere. On the open 100-inch bar, the travel of the disc for an alteration of illumination was considerably larger than on the 60-inch bar; and for this reason the 100-inch bar was an advantage. But if the atmosphere contains fog or any large quantities of suspended matter, it is manifest that the longer the bar, the greater will be the interference of the atmosphere with the

amount of light falling upon the disc. If, however, the time should arrive when the standard and the light to be tested are of nearly the same value, this interference will disappear, and increase in accuracy will be obtained by returning to the 100-inch bar."

The graduations on the photometer bar indicate direct the value of the strongest light in multiples of the weakest, thus saving time and trouble in making calculations, and also avoiding the liability of errors.

As all the photometers in actual use at the present time possess the common feature of having a graduated bar, and as it is of the first importance that these graduations should be correct, it will be advisable, before describing the construction of a photometer in detail, to explain how to graduate photometer bars of various lengths as ordinarily met with.

We will first take a bar 100 inches long. Let x equal the distance from the candle of the point in the bar where the mark is to be made to represent a given number of candles, and let n equal that number, then the number of candles n , multiplied by x^2 , is equal to $(100 - x)^2$, or

$$nx^2 = (100 - x)^2.$$

From this equation the value of x is found to be:

$$x = \frac{100 (\sqrt{n} - 1)}{n - 1}.$$

$$\text{Let } n = 16, \text{ then } x = \frac{100(\sqrt{16} - 1)}{16 - 1}$$

$$= \frac{100(4 - 1)}{16 - 1}$$

$$= \frac{300}{15}$$

$$= 20$$

$$= 20 \text{ inches.}$$

That, therefore, is the place where the mark on the bar is

to be placed to represent sixteen candles. As this mark is 20 inches from the candle, it is, of course, 80 inches from the gas-light. We can check these figures from what we have just learnt, viz., that the square of the greater distance, divided by the square of the lesser, gives the number of candles; consequently $\frac{80^2}{20^2}$ must give the quotient 16 if the above be correct:

$$80^2 = 6400, \text{ and } 20^2 = 400, \text{ and } 6400 \div 400 = 16.$$

The above method will be more clearly understood, perhaps, if stated in words. "Find the square root of the number of candles and diminish that square root by 1. Remove the decimal point two places to the right if there be decimals, and add two ciphers if there be only integer figures, and divide by the number of candles minus 1" (Bowditch). In the case above cited the number is 16, of which the square root is 4, $4 - 1 = 3$. Adding two ciphers gives 300, and 300 divided by $16 - 1$, or 15, gives the quotient 20 inches.

In the improved Bunsen photometer known as the Letheby, the length of the bar was reduced to 60 inches. To find the point of graduation for any required number of candles, it is only necessary to substitute 60 for 100 in the equation already given, and the result will give the distance of the mark from the candle, and for the number of candles required.

One of the latest forms of photometer is shown in fig. 39, as supplied by the well-known firm of A. Wright and Co., of Westminster, who make a speciality of this description of apparatus and of all the accessories connected with the scientific testing of gas.

This form of photometer is known as the Letheby-Bunsen, and the whole apparatus consists of the photometer bar, candle balance, experimental meter, minute clock, experimental governor, King's gauge, standard

burner, sperm candles, and Bunsen disc, with its accompanying disc-holder. A barometer should also be provided. In this form of instrument the graduated bar is of such a length that the centres of the flames to be contrasted are 60 inches apart, the positions of the flames being fixed by means of the plumb-bobs.

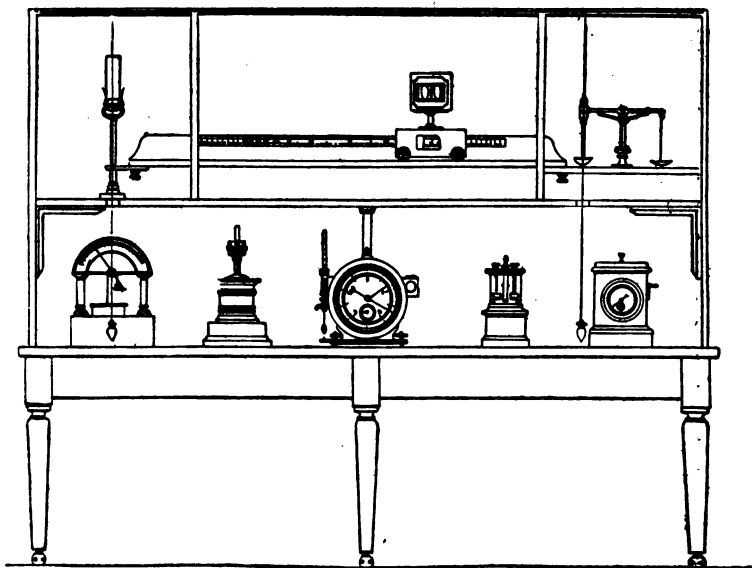


FIG. 39.

The bar is of polished wood, and is graduated each way from its centre into spaces, numbered 1, 2, 3, and so on, to the ends of the two scales thus produced. The centre line, which is called 1, indicates the position at which the disc would be equally illuminated on both sides if the opposing lights at the end of the bar were of equal power, and the divisions "2," "3," and so on, the positions where the

disc would rest when the stronger light was "2," "3," or more times greater than the weaker.

The divisions up to 9 are subdivided into tenths; from 9 to 20, into halves; and from that point they are not subdivided. The bar is mounted at one end on a stiff gas pillar, to which the standard burner is fitted, and at the other end on a wooden table or slab on which the candle balance is mounted, both candle balance and gas pillar being attached to a shelf or baseboard supported, 18 inches above the table, on two side screens; the lights to be contrasted being in a direct line with the longitudinal axis of the bar.

The photometer is further provided with two blackened pinewood screens or shades, having suitable apertures in proper relation to the central line passing through the disc box, and candle, and gas flames respectively; these are fixed as shown in the drawing, so that the outer edges of the screens are, in the case of that at the burner end, 10 inches from the centre of the gas pillar, and at the candle end 5 inches from the centre of the candle holder: there are also four accurate plumb-bobs which are suspended in pairs at each end of the photometer and attached to tie rods in such a position as to denote the true and correct vertical line coincident with the centres of the gas and candle flames respectively, as set and taken from centre lines 60 inches apart, marked upon plates affixed to the base board of photometer.

The disc is enclosed in a disc box with silvered glass reflectors mounted on a polished mahogany saddle or slide, provided with brass rollers or wheels, and carrying a pointer or index directly underneath and in a vertical line with the centre of the disc, the pointer being illumined by means of a reflecting prism.

The candle balance should be of sensitive construction, and capable of weighing to the fiftieth of a grain. In the

arrangement shown in the drawing, which was devised by the late Mr. F. W. Hartley, the instrument is attached to the photometer bar. The end of the beam nearest to the disc box carries a holder for two candles, so that the candles may be weighed *in situ*; it is provided with mechanism at its base for bringing the candles in line with the plumb-bobs.

The experimental meter enables us to determine the rate per hour by the observation of one minute. The minute clock reads minutes, seconds, and hundredths of a minute. It is furnished with a starting and stopping lever at the side, and with a contrivance at the top for instantly bringing the hands to zero. The small dial indicates ten minutes, which is the time occupied in any one set of photometrical readings. The passage of one minute is indicated by the striking of a bell. The governor is for the purpose of accurately regulating the pressure, and is of great sensitiveness; the King's gauge shown is for the purpose of recording such pressure. The standard burner employed will depend upon the special Act of Parliament under which the gas has to be tested.

The only recognized standard at the present time is the sperm candle.

"The Bunsen discs¹ should be made of paper as thin as it is possible to manipulate, and the line of demarcation between the greased and ungreased parts should neither be defined with such absolute hardness as to be distinctly visible in every position between the two lights, nor be softened down so much that in any one position the spot becomes quite invisible."

We will now describe the method of making a test by means of a photometer such as the one described. The first thing to be done before making a photometrical test is to prepare the candles for use. The candles employed

¹ Hartley's "Gas Analysts' Manual."

for gas-testing purposes are known as "sperm candles of six to the pound, each burning 120 grains an hour," and such candles are $8\frac{1}{2}$ inches long from base to shoulder, and the operation of preparing them is commenced by cutting each candle in two at $4\frac{1}{8}$ inches from its base; this is done by laying the candle on a clean smooth board, and rolling it under the edge of a sharp knife. About half an inch of sperm from the lower half of the candle, and the sperm cone from the top half, are then cut away, and the projecting wick of the latter is reduced to half an inch in length.

It is necessary to exercise great care in cutting away the sperm, so as not to injure the wicks in the slightest degree. Each piece of candle is then lit, and held horizontally in one hand over a vessel placed to catch the drops of melted sperm, and is gently rotated for a few minutes, in order to produce what is known as a good cup: the pieces of candle after being treated in this manner are then allowed to burn, not too closely together, and in a place free from draughts, until the flames attain their maximum size and each wick bends over and presents a red point through the flame; they are then gently touched with a small piece of sperm and the flame blown out. "Should any of the candles burn badly, smoke, form very irregular sperm cups about the wicks, or gutter much, they should be rejected, and any candles with the wicks much out of centre should also be rejected."

You now take the upper and the lower halves of one candle, or the lower half of one and the upper half of another candle, and place them in the candle holders of the balance, so that at least an inch of each candle projects above the top of its holder. Warm the sperm about the wick with a lighted taper, and then ignite them. Let the candles burn for at least ten minutes, so that the flames shall attain their maximum size.

The adjustment of the gas to the 5 cubic feet per hour

rate of burning may be effected while the candles are preliminarily burning, the burner employed, if an Argand, being always provided with a clean chimney before every experiment.

The gas examiner may ascertain whether the candles are burning at nearly the normal rate by placing a four grain weight in the candle pan when the balance turns, and observing whether the balance turns again after the lapse of one minute. Before each testing the two candles are to be so placed that the plane of the curvature of one wick shall be perpendicular to the plane of the curvature of the other wick, and the candle balance is to be so adjusted that the axes of both flames shall lie exactly between the two plumb-lines which mark the position of the zero of the scale.

Assuming that the meter is going at the rate of 5 cubic feet per hour, then look to the candles; if they have burned down much push them up until fully an inch projects above the holders. Stop the clock by lifting the lever, and bring it to zero by pressing the button at the top. Nearly counterpoise the candles by placing shot in the candle pan of the balance, leaving the candles a trifle heavier than the counterpoise. Watch the balance until the candles and the opposing weights become equipoised, and the pointer of the balance reaches the centre of its index. Then instantly start the clock by releasing the lever; place a forty grain weight in the pan of the candle holders, and proceed to make your observations in the following manner:

“Move the slide carrying the photometer disc between the gas and candle flames until a position is reached at which the spot on the disc is nearly invisible, or both sides of the disc are equally illuminated.” Observe the graduation mark on the photometer bar on which the pointer of the slide rests, and record the result. When five observations have been made, reverse the disc and mirrors by turning the arrangement through half a circle.

You make ten such observations in a little over nine minutes, then give your sole attention to the candle balance, so that when it again turns, and its pointer reaches the centre of the scale, as it did when the experiment was started, you stop the clock, and note the number of minutes and seconds, or decimals of a minute, the forty grains of sperm occupied in burning.

If the rate of consumption per candle shall not have exceeded 126 grains per hour, which is equivalent to burning the forty grains in nine and a half minutes, or nine minutes thirty seconds, or shall not have fallen short of 114 grains per hour, which is equivalent to burning forty grains in ten and a half minutes, or ten minutes thirty seconds, then calculations may be made in order to neutralize the effects of the divergence from the standard rate of 120 grains per hour; but if the rate of consumption shall have varied from the prescribed rate beyond the above-named limits, then the testing is to be rejected, and a fresh testing made.

We will now suppose that the ten consecutive readings were as follows:

7.40

7.40

7.45

7.50

7.50

7.60

7.60

7.60

7.70

7.70

 10) 75.45

 7.545

The mean of the ten readings is therefore 7·545, which multiplied by 2 (because two candles were employed) would give 15·09 as the illuminating power of the gas; but this would have to be further corrected for the consumption of the candles if each of the latter did not burn at the exact rate of 120 grains per hour, and for the barometric pressure and temperature, as well as for the consumption per hour as indicated by the experimental meter if the latter did not burn at the exact rate of 5 cubic feet per hour.

There should be no difficulty in adjusting the rate of gas to 5 cubic feet per hour, and it should not be necessary to make a correction for this; but should it be necessary to do so, then the rule is, multiply the average illuminating power by 5, and divide by the actual rate; thus, supposing that the rate of burning was 5·1 cubic feet per hour in place of 5 cubic feet, then in the present example:

$$\begin{array}{r}
 15\cdot09 \\
 5 \\
 \hline
 5\cdot1 \overline{)75\cdot45} \\
 \text{Corrected average } 14\cdot79
 \end{array}$$

In order to correct for the consumption of the candles, multiply the average illuminating power (after correcting for the gas consumption if necessary) by the standard rate in seconds, and divide this result by the *actual* time of burning.

Thus, supposing in the present experiment that the candles occupied ten minutes fourteen seconds to burn the forty grains of sperm, in place of ten minutes (the standard time) then

$$\frac{14\cdot79 \times 600}{614} = 14\cdot45 \text{ candles.}$$

In order to correct for barometric pressure and temperature, multiply the corrected average as just obtained by 1,000, and divide the result by the tabular number in the Gas Referees' table constructed for this purpose, in line with the observed barometric pressure, and under the observed temperature, as indicated by the thermometer inserted in the meter.

There is another type of photometer also employed in gas testing, known as the "Evans," from the name of its inventor.

The type of photometer known as the "closed Evans" was introduced in 1858. It consists of a long box enclosing the candles and the light to be tested. The disc was fixed and the candles were mounted on their balance, which moved in a travelling holder attached to an endless cord working with a small winch.

The only legal standard at present authorized for the testing of gas has long been considered unsatisfactory for many reasons, and at the present time a committee of specialists are studying the question as to which is the most reliable substitute.

The following remarks by Professor Lewes, who is the secretary of the committee who are investigating the question will be of interest to the student :

"Ever since Bouguer introduced the candle as a standard of light, it has held its own, in spite of the extremely unsatisfactory results which are to be obtained from it; and it is useless to strive after scientific accuracy with the remaining parts of the apparatus while the standard itself is liable to such wide variations as to absolutely nullify the results obtained by its use. Up to 1850, no definition seemed to exist as to what the candles were to be that were used for gas testing. In that year, however, an Act was passed in which wax candles were prescribed for this purpose; and in 1860 the Metropolis Gas Act defined and

prescribed sperm candles of six to the pound, each burning 120 grains per hour, in place of the wax candles previously used. These sperm candles emitted more light than the old wax candles—fourteen sperm candles being equal to sixteen wax ones. It was found, however, impossible to use pure spermaceti; and in order to prevent crystallization of the spermaceti, from 4 to 5 per cent. of beeswax had to be mixed with it. Slight variations in the quality of the sperm and the method of admixture, and changes in the process of manufacture, will sometimes tend to slightly alter the results obtained with such candles. The weak point of the candle, however, which has led to endless trouble, and which renders it absolutely unfitted to be looked upon as a standard of light, when used according to the ordinary prescribed methods, is the wick—the roughness or smoothness of which, and its curvature during burning, causing extraordinary variations in the light emitted by it, even supposing that the wicks could be made absolutely uniform, the twist of the thread kept constant, and the same amount of strain placed upon them during the making of the candle.

“It has been conclusively shown by Mr. W. C. Young that the standard sperm candle may be relied upon to give very uniform results, if due regard is paid to the condition and shape of the wick before commencing an experiment. But inasmuch as the method by which this desired end could be brought about is not in accordance with the instructions of the Gas Referees as to the mode of using the candle for testing gas, it is useless to discuss the question; and one can only agree with the various Committees who have considered the subject of standards of light, all of whom are unanimous in condemning the sperm candle as not being in any way reliable. In spite, however, of the torrent of abuse which during the past fourteen years has been showered upon the sperm candle and the numerous

complications to which it has given rise, the difficulty of finding a standard which should be more reliable, and yet be as convenient to employ, has been so great that the candle still survives as the only legal unit of light, although many attempts have been made to replace it by something more satisfactory. Another reason for the survival of the candle is that the attempted improvements in the manufacture of sperm candles have in all probability resulted in their emitting a small fraction less light than was the case with those in use at the time of the passing of the Act; and the vested interests of the gas companies is so strong that they are able to successfully oppose any alteration of the standard which would in any way tell against them.

“Attempts have from time to time been made by the Gas Referees to render the method of using the candles more accurate. In their earliest ‘Notification,’ some eight years after the sperm candle was legalized, they prescribed that ‘the candles are to be lighted at least ten minutes before the beginning of each experiment, so as to have arrived at their normal rate of burning, which is shown when the wick is slightly bent and the tip glowing.’ In 1877 this direction was altered so as to read: ‘The candles are to be lighted at least ten minutes before the beginning of each testing, so as to have attained their normal rate of burning;’ and it was also ordered that all testings were to be rejected where the candles burnt more than 126 or less than 114 grains per hour. No further alteration took place until 1889, when, the Gas Referees’ attention having been drawn to the great differences ascribed to the illuminating value of the gas by variations in the position of the wicks, the relative positions of the candles and wicks were for the first time defined; and it was also prescribed that the gas examiner should use a different candle for each test made. All this, however,

has proved perfectly inadequate to make the candle into a satisfactory standard.

"The most convenient standard of light, and the one most used for practical testing in gas-works, is the Methven screen, first introduced in 1878, which consists of an upright rectangular metallic plate fixed in front of a 'London' Argand burner. The upright plate has a slot which is covered by a thin silver plate, having a vertical slot of such dimensions as to allow of the passage of as much light as equals that afforded by two average standard sperm candles, when the Argand burner is provided with sufficient gas to give a flame 3 inches in height. It is manifest that, when used with coal-gas, it is only within certain limits that one could rely upon a small portion cut out of the original flame emitting a practically constant light; and that, although these limits are well within the illuminating value of the London gas supply, it is still very advisable to obtain greater constancy in result, which is done by using an aperture of smaller area, and carburetting the coal-gas in the burner with pentane.

"Perhaps the most important of all the proposed standards was Mr. Vernon Harcourt's 1-candle pentane unit, first described by him at the meeting of the British Association for the Advancement of Science in 1877. The gas used for this standard is made by bringing together, in a gas-holder, air and liquid pentane, which evaporates and mixes with the air, in the proportion of 1 cubic foot of air and 3 cubic inches of pentane. The pentane to be used is a mixture of pentane with some of the paraffins of lower and higher boiling-points, which is prepared by distilling the light petroleum at 60° C., at 55° C., and twice at 50° C. The pentane thus prepared must satisfy the following tests:—On agitation with one-twentieth of its bulk of fuming sulphuric acid for five minutes, it must impart to the acid only a faint brown colour. Its liquid density

must be between 0·62 and 0·63 at 62° Fahr. The liquid must evaporate at the ordinary temperature absolutely without residue when the tension of its vapour is not less than 7·5 inches of mercury. The density of the vapour compared with air must not be less than 2·47, nor greater than 2·53.

“The standard 1-candle pentane unit burner consists of a brass tube 4 inches in length and 1 inch in diameter, which the gas enters towards the bottom. The upper end of the tube is closed by a brass plug, half an inch in thickness, in the middle of which is a round hole, a quarter of an inch in diameter. Around the burner is placed a glass cylinder, 6 inches by 2 inches, the top of which is level with the top of the burner—air entering through the gallery on which the chimney stands. Above the burner is supported, at a height of 62·5 mm., a piece of platinum wire about 0·6 mm. in diameter, and from 2 to 3 inches in length. The air gas passes through a small meter delivering at each revolution one-sixtieth of a cubic foot, and then through a small governor fitted to regulate the flow to half a cubic foot an hour. The height of the flame is adjusted by means of a delicate stopcock, until the top of the flame appears to touch, but not to pass, the horizontal platinum wire, which is adjusted so as to be exactly over the flame, and to extend not less than half an inch beyond it.

“In practice, the great drawback to this unit is that it is very difficult to get two observers to adjust the height of the flame exactly alike, and also that it is very easily affected by draughts and by vibrations; and it also appears preferable to use a standard which shall be more nearly that of the light which is to be tested. To fulfil these conditions, Mr. Dibdin has proposed a 10-candle pentane Argand, burning fully pentanized gas or air. It consists of a specially constructed Argand burner, giving a slightly

bellied flame, the top of which is cut off by a screen exposing a fixed height of flame; and this burner, from the constancy of the results obtained, the ease of manipulation, and the small extent to which it is affected by external causes, seems likely to take the place of candles should these unreliable standards ever be discarded.

“The Harcourt screened lamp consists of a vessel, somewhat like an ordinary spirit-lamp, which contains the oil or liquid with which the wick is fed. This liquid is again pentane, derived from petroleum by repeated rectification. Fastened to the vessel containing the pentane is a tube, through which the wick is passed, and which is fitted with an ordinary double-spiked wheel turned with a handle for regulating its height. Another tube surrounds the wick-tube, and answers the purpose of keeping the latter cool, and also of steadying the current of air supplied to the flame. A metal chimney surrounds the burner and the lower part of the flame, and is connected with the upper chimney by curved metal bands, sufficiently removed from the flame as not to affect it. Through the space thus left between the upper and lower chimneys, the central part of the long flame is alone visible; and the opening can be regulated so as to yield a light equal to $\frac{1}{2}$, 1, or $1\frac{1}{2}$ candle as desired. The lamp is in reality an improved amylnate lamp, but burning pentane; and only a portion of the flame is taken for the standard.”

CHAPTER XV.

THE METHODS EMPLOYED FOR CONTROLLING PRESSURE AT THE WORKS SO AS TO SECURE AN ADEQUATE SUPPLY OF GAS AT THE VARIOUS POINTS OF CONSUMPTION, WITH A DUE REGARD FOR ECONOMICAL EFFECT.

IN order that the gas may be delivered on the district from the works at a uniform pressure at all periods, and independent of any fluctuations in the consumption, it is necessary to employ the instrument known as the station governor. The instrument is placed between the gas-holder and the distributing main, and serves, in the first instance, to reduce the pressure thrown by the various gas-holders (which is generally in excess of the requirements for the proper supply of the district) to the pressure which is just sufficient for such supply, and also to keep the pressure required at any particular period constant, automatically adapting itself, when once set to a stated pressure, to the varying fluctuations of consumption on the district, in other words it "governs" the pressure, hence its name of "governor."

The governor as frequently met with is shown in fig. 40, and consists of a tinned iron gas-holder, floating freely in a cast-iron tank, and having suspended from its crown a parabolic plug. The inlet pipe for the gas is exactly in the centre of the tank, and finishes at the top in a conical-seated flange which exactly fits the parabolic

plug. The outlet pipe is concentric to the inlet pipe and rises some distance above the level of the water. The holder is provided with an annular float of such buoyancy that when the tank is charged to the proper water-line it rises, carrying with it the suspended parabolic plug, and, supposing all the weights on the top of the holder to be removed, the holder would ascend to its full limit, and in so doing would cause the parabolic plug to completely fill the orifice in the inlet pipe, and would thus shut off the

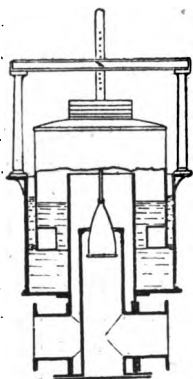


FIG. 40.

supply of gas, when, of course, the governor would not give any pressure; but supposing we required to give a certain pressure on the district, say, fifteen tenths; then on placing weights equivalent to that amount on the top of the holder, the holder would descend, and with it the conical plug which would open the orifice at the top of the inlet main to the extent requisite to allow sufficient gas to give the pressure required to escape, and no matter what variations may take place in the pressure at the works, or the amount of gas consumed on the district, the same pressure is rigidly

maintained by the governor at its outlet; for in the event, say, of a sudden draught on the main owing to an increased consumption, the pressure in the main would be reduced, and as the governor and holder communicate by means of the outlet pipe with the district main, this reduced pressure would cause the governor holder to descend; in so doing the parabolic plug would also descend and open the gas-way more, thus causing more gas to pass through the valve opening, and in this way maintain the pressure at that originally intended; on the other hand, should the

consumption on the district slacken, then the pressure in the main would increase and back up as far as the governor, where it would lift up the holder, which would at the same time lift up the suspended plug higher into its seating, thus reducing the gas-way, and consequently the pressure on the district. Of course, the governor is not intended to control the initial pressure which is required for supplying the district, the pressure required at any particular time being regulated by the addition or taking off weights from the crown of the holder.

As previously remarked, the holder is buoyed up by means of an annular float, the same result can be attained by attaching a chain to the crown of the holder on the outside; the chain passes over one or two pulleys, and terminates in a rod which carries weights sufficient to counterbalance the holder, and by taking weights off this rod, the latter operate in the same manner as if they were placed on the top of the holder.

The valve which increases or decreases the area of the gas aperture is made in the form of a parabola, on account of the latter form of valve producing the effect desired within a shorter range, and also by reason of its being more delicate and reliable in its action.

"The parabola should be made twice its diameter in length, and of weight sufficient to resist, without oscillation or blinking, whatever pressure may be exerted against it by the inflowing gas" (Newbigging).

Now all forms of governors of the kind just described, and which are classed as "cone valve governors," possess one great disadvantage, viz., they are all liable to oscillate when variations occur in the inlet pressure, which may be caused either by the bringing into action gas-holders of different weights, or by the cupping and uncupping of telescopic holders. The variations of the inlet pressure acting upon the base of the valve sets the latter moving,

this is communicated to the bell of the governor, with the consequence that "blinking" ensues, which is very annoying. Another cause of governors not being steady is by having the gas communications of a much larger area than is really required. In order to overcome these defects various devices have been designed, one of the most successful being that of reducing the size of the pipe communicating with the holder, and which, in the majority of cases, need not be more than about an inch in diameter,

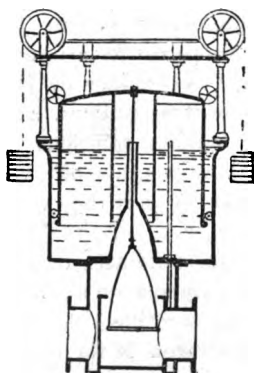


FIG. 41.

and also by arranging that the inlet pressure acting on the valve is balanced by a similar pressure acting on the other side of the valve. In the governor patented by Messrs. J. and J. Braddock the last-mentioned result is arrived at in the following manner, fig. 41 :

"The gas enters the base of the governor, passing over the valve and downwards into the valve chamber to the outlet. Fixed to the centre of the crown of the holder is a chamber like an inverted canister with the cover removed, which is always sealed in

the water in the tank, and does not communicate in any way with the governor holder, and is of exactly the same sectional area as the base of the valve. This compensating chamber communicates directly with the inlet portion of the governor, and is subjected to the same pressure as the valve. Now supposing the inlet pressure is suddenly increased, this acting upon the valve tends to push it downwards, and so increase the gas-way, but as the same pressure exerts itself upon the same extent of area against the crown of the holder inside the com-

pensating chamber, and tends to raise it, a state of equilibrium is produced, and the position of the valve kept constant" (Herring).

Mr. C. Hunt, the late Examiner in Gas Manufacture to the City Guilds of London Institute, has invented a governor which works on a different principle to those just described, by adapting the ordinary throttle valve to the purpose of a governor. This method possesses the advantage that a gas-holder scarcely larger than the main is only required.

The construction of the apparatus is as follows, fig. 42:

Within the supply main leading from the works to the district, a disc or throttle is accurately balanced on two small steel centres, the lever by which the disc is moved being also inside the main, and attached to the centre of the disc. A small vertical pipe places the holder in communication with the main, and serves to inclose the lever which is attached to the disc and to the crown of the holder, and also conveys the gas into the latter.

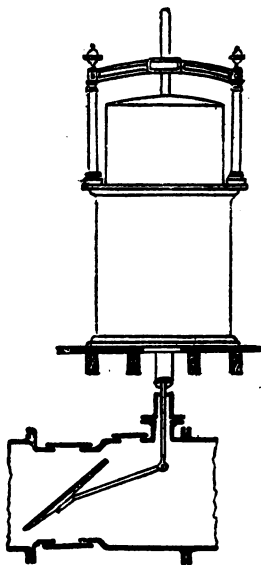


FIG. 42.

The governor of Messrs. W. and B. Cowan, shown in fig. 43, possesses many distinguishing features. In place of the parabolic valve of the ordinary cone governor a hollow cylindrical valve is employed, which is closed at the bottom but open at the top. Around the sides of this valve a series of conical ports are formed, and this arrange-

ment permits the governor to be in perfect action while only passing an extremely small volume of gas.

A further advantage with this form of valve is, that by reason of its being accurately fitted in its surrounding seating it is only capable of a free vertical motion, whereas the parabolic valve, being suspended, is free to move sideways. In order to counteract the influence of the inlet pressure on the base of the valve the following arrangement is employed :

On the crown of the governor holder an annular tank is fixed, and into this latter a bell or holder, suspended from, and fixed to, the cross-bar of the governor guides, dips. The diameter of this bell corresponds with the diameter of the valve below, and forms, with the annular tank, a water lute, which incloses an area equal to that of the valve base. The hollow rod which suspends the valve also conveys the gas from below the valve base, or from the inlet side of the governor, to the interior of the chamber inclosed by the water lute, and exerts the same pressure above the bell of the governor. In this way the inlet pressure is exactly equalized on each side of the valve. The gas is supplied to the governor bell from the outlet side by means of the centre tube, which terminates a little above the water-line, and through which the valve rod passes.

In addition to improving the construction of the governor itself, Messrs. Cowan have made a decided advance in the method of working the same, *i.e.*, by the employment of water in place of weights for the purpose of putting on and taking off the pressure; by this arrangement the pressure is imperceptibly changed, whereas in the old way of regulation, by weights, even when carefully performed by increasing and decreasing the pressure very gradually, the change of pressure was frequently observable on the district. The water-loading apparatus for increasing the pressure, and Cowan's patent stationary syphon for the removal of

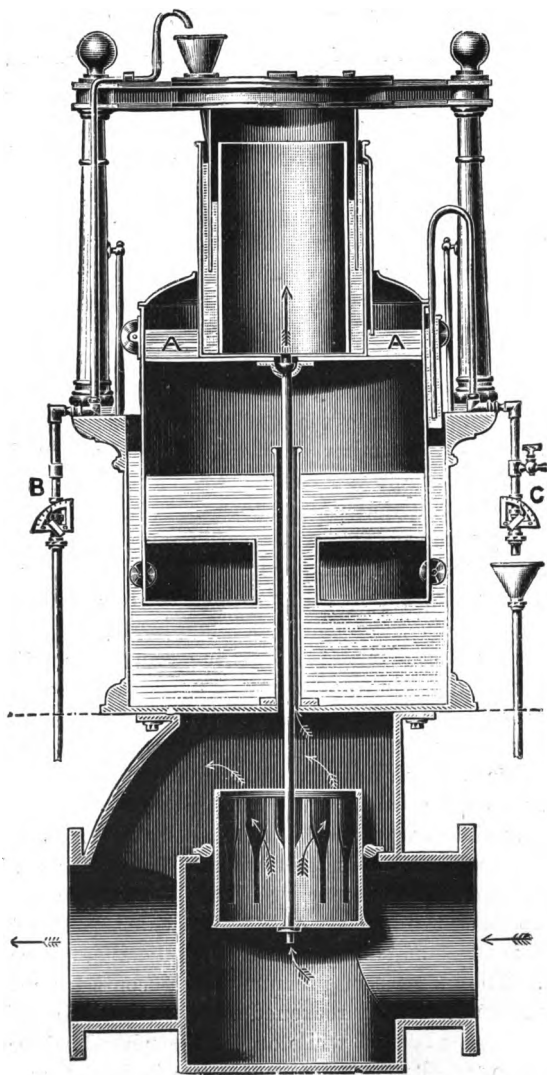


FIG. 43.

the water from the water-loading tank, when reducing the pressure, are shown in fig. 43: *B* being the pipe conveying the water for loading; *A* the water-loading tank; and *C* the syphon for the removal of water. Messrs. Cowan have also devised a method for automatically regulating the pressure on a district by means of their "Automatic Pressure Changer," shown in fig. 44.

The apparatus consists of a clock, having geared to it a disc, which it revolves once in twenty-four hours. Attached to this disc are two series of tappets, which can be so fixed as to come into operation at any desired period of the disc's daily revolution. One set of tappets controls a cock supplying water to the loading tanks of the governor bell, the other, a similar cock, withdrawing water therefrom. Shutting off the flow of water when the required addition or reduction of pressure has been attained is effected by means of two small gas-holders placed in communication with the outlet gas. One of these in rising causes the water supply cock to close, the other in falling, the syphon cock.

The weighting of these holders is arranged so as to increase or diminish in steps, as they rise or fall, the pressure required to actuate them during each stage of their travel corresponding to that which the governor is desired to give. The various tappets do not directly actuate the cocks, this duty being performed by means of suitable weights, which are wound with the clock once a week.

In places where the district supplied varies in level, it is often necessary to place governors at various points, in order to check the increase of pressure which would otherwise take place at parts elevated some distance above the works. The increase of pressure which occurs from a rise in elevation is usually reckoned as a tenth of an inch of water for every 10 feet, while on the other hand, where the gas has to travel to a *lower* level, a *loss* in initial pressure

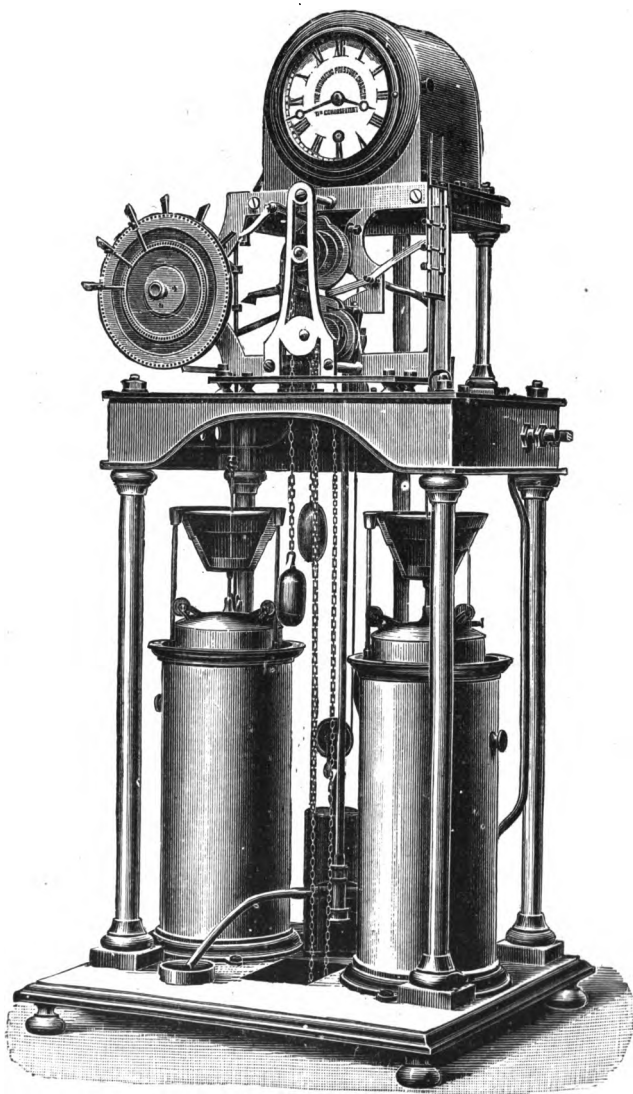


FIG. 44.

takes place in the proportion of a tenth less pressure for every descent of 10 feet. District governors for the automatic regulation of the pressure in the mains at high altitudes are made both in the wet and dry form. Fig. 45 shows the arrangement adopted by Messrs. D. Bruce, Peebles and Co.

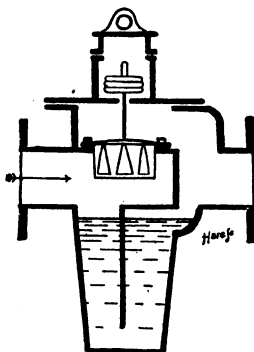


FIG. 45.

The operation of controlling the pressure by means of the governor, to the lowest amount consistent with the granting of a sufficiency for the adequate supply of the district, is one of the greatest importance, as upon this depends in a great measure the amount of unaccounted-for gas through leakage from the mains and service pipes, a pressure greatly in excess of that necessary for the requirements of the district, involving a heavy leak-

age account, as "by doubling the amount of pressure, the consumption of gas is increased by about one-half. Leakage from a pipe is, of course, increased in the same ratio, i.e., in the proportion of the square root of the pressure" (Newbigging).

CHAPTER XVI.

THE LAYING OF MAINS AND SERVICE PIPES.

THE pipes which convey the gas through the various streets and thoroughfares are known as main pipes or mains, the smaller pipes leading from the main pipes, and which convey the gas to the consumers' premises, etc., being known as services.

The material of which gas mains are made is usually cast iron, although in some instances, as in the laying of a trunk main, they are constructed of riveted wrought-iron or steel plates.

As the leakage which occurs in the distribution of gas is caused in a great measure by defective and badly-jointed mains, it is necessary to see that the pipes employed are made from iron of good quality, that the metal possesses a close grain, but is not too brittle, and that the sectional thickness of the pipe is equal throughout its whole length, and generally, that the pipes are free from defects of every description.

With this aim, all cast-iron pipes having an internal diameter of 5 inches and upwards should be cast vertically in dry sand moulds.

All pipes should be tested by hydrostatic pressure equal to 80 lbs. per square inch, and whilst under this pressure they should be rapped from end to end with a light hammer, which will often detect faults. Should there be any cracks or flaws, these will be shown by the water

oozing therefrom, in which case the pipe should be at once rejected.

A sound pipe may easily be distinguished from a cracked one, by the clear bell-like sound it gives when smartly struck with a hammer.

Pipes as ordinarily made, when under 3 inches in diameter, are 6 feet long, and about three-eighths of an inch thick; when under 12 inches and above 3 inches diameter, they are 9 feet long, varying in thickness from three-eighths to half an inch; when 12 inches diameter or larger, they are made either 9 feet or 12 feet long, but do not often exceed 1 inch in thickness. The socket is not included in the lengths just given. Pipes of smaller diameter than 3 inches are usually of wrought iron.

Mains are laid in trenches which sometimes require to be shored and strutted; the pipes are lowered into position by means of a chain and pulleys suspended from shear legs, which rest upon planks placed on the edge of the trench.

There are two methods of jointing gas mains in general use, viz., the "open lead," and the "turned and bored" joint.

In both descriptions of joints the pipes are cast with a socket at one end sufficiently large in diameter to allow the end of another pipe to freely enter it, the entering end being known as the "spigot." Pipes which are intended to be connected by means of "turned and bored" joints have the inner face of the socket and the outer face of the spigot turned perfectly true in the lathe, and with an exceedingly slight amount of taper. Fig. 46 shows an "open socket," and fig. 47 a "turned and bored" joint. The sockets vary in depth from $2\frac{1}{2}$ inches for 2-inch pipes, to 6 inches for pipes 36 inches in diameter.

When making an open lead joint, the spigot of the pipe about to be laid is placed into the socket of that already laid, leaving an annular space between the spigot and the

socket of about half an inch in thickness, which is filled up with molten lead in the following manner. The inner portion of the annular space is first filled with tarred gasket or spun-yarn to about half the depth of the socket, and driven well in with a caulking tool. The outside face of the joint is then tightly closed by means of a belt of plastic clay, which completely encircles the pipe, and presses up against the face of the socket, leaving an opening known as the "lip" on the upper side of the pipe for the purpose of pouring in molten lead, which fills up the remaining space inclosed by the clay and tarred yarn. When this space is filled up with the lead, the excess of the latter

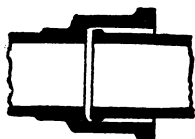


FIG. 46.

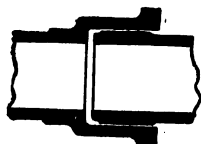


FIG. 47.

flows over at the lip, when the clay is removed and the joint "set up" with a thick caulking iron, known as a "set," by means of which the ring of lead is wedged sufficiently tight to prevent the escape of gas.

When running such a joint as the one described, care must be taken that the spun-yarn is not wet or damp, otherwise the joint will "blow." It is a good plan in such an event to place a small piece of tallow in the "lip" before commencing to run the lead.

It is further necessary to exercise care, when making such joints, not to have an excess of lead on the outer part of the joint, or what is known as "too full" a joint, as it may happen that in "setting up" the socket may split; the same result may also occur if the joint is not full enough, the socket sometimes splitting by the wedging

in of the caulking tool. A lead joint when properly set up should present a smooth unbroken surface all around the pipe.

In laying turned and bored pipes, all that is required is to clean the turned faces and smear them over with a mixture of red and white lead; the spigot is then inserted and driven home either with a mallet or by a pipe suspended to shear legs. It is very necessary to see that the turned and bored faces of the spigot and socket respectively are quite clean before painting them with the mastic.

With regard to the relative advantages of these two descriptions of joints, the "open lead," owing to its being more elastic, is better adapted for sweeping round curves, and the pipes themselves are cheaper; but the turned and bored are cheaper to lay in the first instance, and are readily taken to pieces again; on the whole, however, the balance of opinion seems to be in favour of the open lead joint.

The durability of mains depends in a great measure upon the nature of the soil in which they are laid, the best material for this purpose being clay, whilst the worst description is ground which contains ashes, clinker, etc.

All pipes should be laid at a depth of not less than 2 feet, in order to lessen the liability to fracture, and to counteract the influence of our changeable climate. "The body of each pipe should rest evenly upon the bottom of the trench, a pocket being excavated under the socket to allow of making the joint."

In order to prevent the main becoming water-logged by the deposited condensed water-vapour, it is essential that each pipe be laid with a proper inclination or fall, on no account being placed perfectly level. Where the road itself is on an incline this is an easy matter to arrange, but where the road is level the pipes should be so laid that they have a fall of say 1 foot in 400 yards.

At each of the lowest points in the length of the road, cast-iron receivers or syphons should be provided for the purpose of collecting all the condensed products. These are shown in figs. 48 and 49, and, as will be seen, each is provided with a wrought-iron stand-pipe, which passes down to within about an inch of the bottom of the vessel, for the purpose of attaching a syphon pump for periodically pumping out the accumulated condensed products.

In order to arrive at the size of mains required for different quantities of gas under different conditions, we

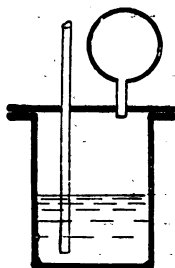


FIG. 48.

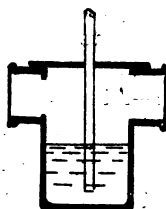


FIG. 49.

are mainly indebted to the formula given by Professor Pole in his excellent article "On the Motion of Fluids in Pipes," as given in King's "Treatise on Gas Manufacture," vol. ii. p. 374.

The formula is as follows :

$$Q = 1350 d^2 \sqrt{\frac{h d}{s l}}$$

Q = quantity of gas in cubic feet per hour.

l = length of pipe in yards.

d = diameter of pipe in inches.

h = pressure in inches of water.

s = specific gravity of gas, air = 1.

The above expressed in words would read :

Multiply the pressure in inches of water by the diameter of the pipe also in inches. Divide the product by the specific gravity of the gas multiplied by the length of pipe in yards. Extract the square root of the quotient, which root, multiplied by the constant quantity (1350) and the square of the diameter of the pipe in inches, gives the number of cubic feet discharged per hour.

It is sometimes necessary when attaching a branch to or relaying a live main, to temporarily shut off the flow of gas from the latter at the point where the alteration is being made, and in the event of both ends of the main where the relaying is taking place being charged with gas, as when a system of mains is connected together, it will then be necessary to cut off the gas flow on either side of the intended new connection. This is generally effected as follows:—At a short distance from the point where the main will be severed a hole is drilled in the pipe, the hole being afterwards tapped. An india-rubber gas-bag (fig. 50), provided with a length of tube and a tap, is then inserted into the hole, or in the case of a small main, a bullock's bladder, which has been previously rendered supple by being well soaked in oil. The india-rubber gas-bag, when fully inflated, assumes a spherical shape, as shown. When the bag has been inserted in the main, the hole through which the tube passes is surrounded with clay, and the bag inflated by means of a pair of bellows, and when fully distended the tap is closed. This arrangement has the effect of completely shutting off the gas from the main, by reason of the distended bag pressing tightly all round the inside of the pipe; but with large mains it is advisable to use two such bags, one behind the other.

The same method is adopted at the other end of the main. When the work of relaying is completed, the taps on the bags are opened, which allows the air to escape,

when the collapsed bags are withdrawn through the small holes; the bag at one end being withdrawn first, and the gas thus admitted allowed to force out the air contained in the main, before withdrawing the bag at the other end, the air thus forced out being got rid of at a stand-pipe placed near the bag at the other end of the main. When it is considered that all the air has been expelled the remaining bag can be taken out, plugs being screwed in the holes through which the bags were inserted.

A useful apparatus in the relaying of mains is the patent pipe extractor, invented by Mr. Helps, of the Gas-Works, Croydon.



FIG. 50.

It is frequently required to test a live main for soundness, in order to trace out leakages, and various methods have been devised for effecting this object.

The late Mr. Brothers devised an apparatus for this purpose which simply consists of two 30-light meters, one of which registers the passage of the gas in the usual way, while the other is made to act as an exhauster, either by continuing the spindle of the drum through the meter case, and attaching a handle to it, or by means of a small wheel geared into a larger one on the periphery of the drum, the former being worked by a handle from the outside. The main having been severed, and the two ends carefully

plugged, the exhauster inlet is connected to the live main, and the meter outlet to the dead section of main, the exhauster and meter also being joined. On the exhauster being gently turned, gas is drawn from the live main and forced through the meter into the length of main under test, thus indicating the amount of loss in a certain time and under a given pressure. The main is divided into sections, the supply to each being cut off in rotation.

The laying of mains and services embraces both the laying of mains on the district and the mains on the gas-works itself. It will therefore be necessary to say a few words concerning the latter.

Works mains are usually jointed together either by means of the open socket joint or by the flange system, which consists in having projecting flanges cast on either end of the pipes which require connecting, the flanges being either faced and bolted together, or a piece of mill-board is inserted between the two flanges. Flange joints are most frequently employed when it is required to connect a main to a valve, or in a position above the ground, as, being rigid, the flange joint is apt to be fractured should any settlement of the ground occur. For this reason, flange joints are not employed in the laying of mains on the district.

As mentioned under condensation, the gas, as it leaves the hydraulic main, carries in suspension a considerable quantity of aqueous vapour, but as the temperature of the gas during its passage through the various apparatus from the retort-house to the outlet of the scrubbing plant becomes reduced, the greater proportion of this aqueous vapour becomes condensed to the liquid form; but even after leaving the last-mentioned apparatus, a certain quantity of aqueous vapour still remains, the quantity mainly depending upon the atmospheric temperature prevailing at any particular time, as the warmer

the temperature the more aqueous vapour the gas is capable of holding in suspension; so that although the greater part of the aqueous vapour is deposited during condensation, etc., a portion remains which condenses afterwards, and is met with at all points of the works' mains and on the district mains also, as previously described. It is necessary, therefore, to get rid of this deposited water which otherwise would block the mains and obstruct the flow of gas; for this reason the mains should be laid with a slight fall in order that the liquid may run to suitable points. The amount of fall, as a general rule, should not be less than half an inch in each 9 feet length of pipe, and, if possible, it is advisable to give an inch fall in the same distance, more especially if much tar deposits in the main.

At the various lowest points, such as at the inlets to the exhauster, the washer and scrubber, and the purifiers, large receivers should be provided, into which all the products of condensation may drain, the accumulated liquid being periodically pumped out. This periodical pumping must be strictly attended to, otherwise the mains will become logged; it will be necessary therefore at some points of the mains to pump these receivers several times in the course of twenty-four hours.

It is very important to arrange the mains so that the gas can slip past any of the apparatus on the works. This is effected by means of bye-pass connections, the "bye-pass" being a main connecting the inlet and outlet of an apparatus, valves being fixed on the inlet, outlet, and on the main between. When an apparatus is working normally, the valve on the bye-pass is shut, and those on the inlet and outlet are open, but should a stoppage take place, then, by opening the bye-pass valve, the gas has a free course past the apparatus, and, on closing the inlet and outlet valves, the obstruction can be cleared.

The various changes required in altering the direction of

flow of gas are made by means of valves of which there are various descriptions, hydraulic and slide, the latter, also known as the disc valve, being the most common and convenient. As generally employed, they are worked by means of a rack and pinion, which raises or lowers a disc which closes or opens the gas-way. Figs. 51, 52 show such a valve when shut and also when partly open. The gas-way of the valve is of the same size as the main to which it is attached,

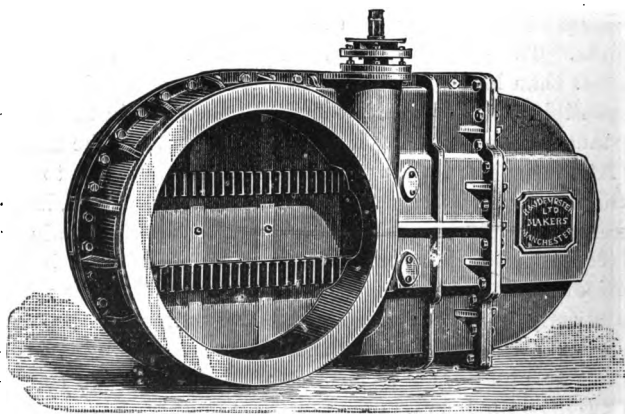


FIG. 51.

and that part of the valve against which the disc slides is accurately planed and faced, the disc being pressed against the face of the valve by means of a strong spring and a series of wedges, so as to keep it perfectly gas-tight; the valve being fixed so that the pressure of the gas will be at the back of the disc. When the disc is being opened it slides into the side chamber shown in the figure, the pinion wheel which works the rack being also inside the valve-case, so that the spindle of the pinion which projects through a gland outside the valve-case is the only portion exposed.

SERVICES.

The material generally used for services from the mains to the consumer's premises or public lamps is wrought-iron tubing, which should always be of the best quality procurable. The different parts which are employed in the various descriptions of service laying are shown in

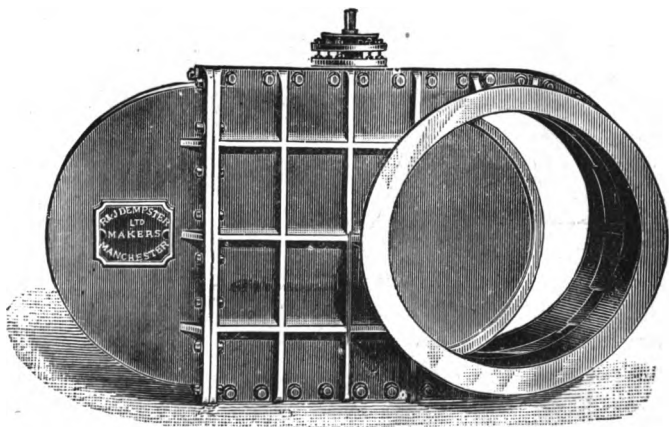
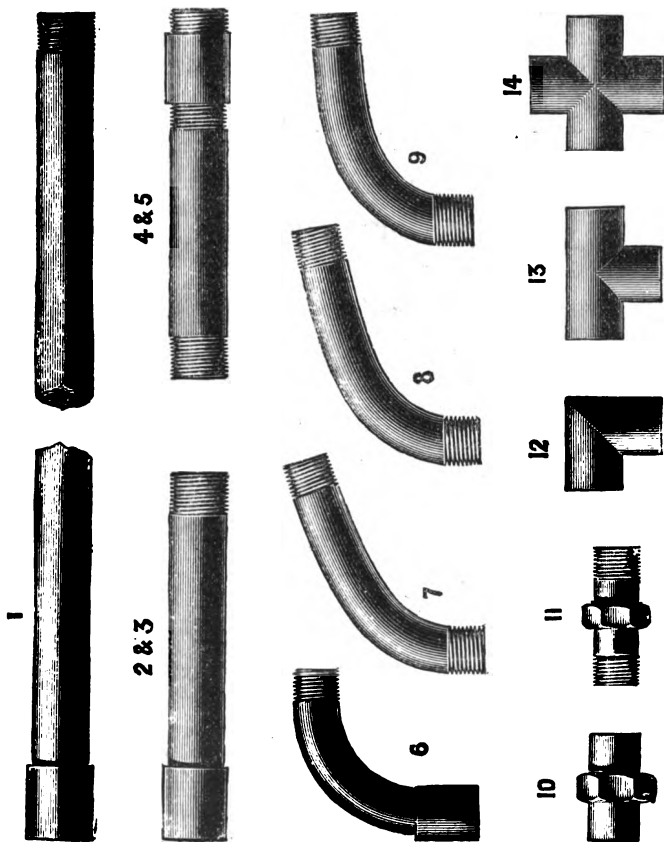


FIG. 52.

Plate IV., from which it will be seen that the connections are all made by means of male and female screws.

Lead service pipes are also employed in some instances, but these require to be carefully supported throughout their length in order to prevent sagging and the resulting accumulation of water.

In order to preserve the iron tube used in service laying, the pipes may either be coated by the Bower-Barff process, or be heated and afterwards well coated with tar, or where the soil is very destructive the system employed by the



Tubes.

No. 1. Tubes 2 to 14 feet long.
 " 2. Pieces 12 to 23 $\frac{1}{4}$ inches long.
 " 3. Pieces 3 to 11 $\frac{1}{4}$ inches long.

No. 4. Long screws 12 to 23 $\frac{1}{4}$ inches.
 " 5. Long screws 3 to 11 $\frac{1}{4}$ inches.

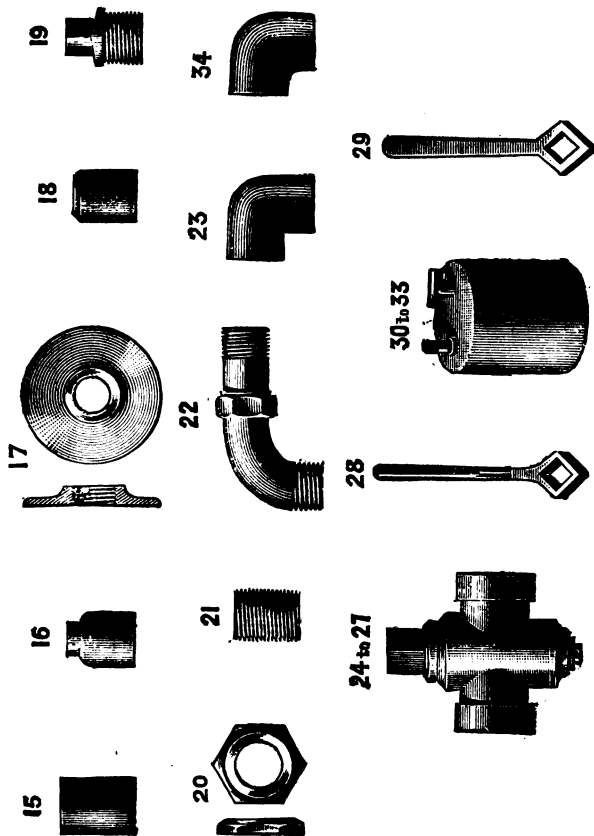
No. 6. Bends.

" 7, 8, 9. Springs not socketed.

Fittings.

No. 10. Socket union. | No. 11. Pipe union.

No. 12. Elbows. | No. 13. Tees. | No. 14. Crossef.



Fittings.

No 15. Plain sockets.
 " 16. Diminished sockets.
 " 17. Flanges.
 " 18. Caps.

No. 19. Plugs.
 " 20. Back-nuts.
 " 21. Nipples.
 " 22. Union bends.

No. 23. Round elbows.
 " 24 to 27. Main cocks.
 " 28 29. Spanners for do.
 " 30 to 33. Syphon boxes.

No. 34. Malleable cast round elbows.

PLATE IV.

Gas Light and Coke Company should be adopted. This consists in having a rudely made trough formed by two wooden battens $2\frac{1}{4}$ or 3 inches wide and $\frac{1}{2}$ inch thick nailed together, which is laid beneath and almost touches the service, when it is filled with hot pitch or a mixture of tar and sand which entirely covers the pipe, so that it is thoroughly embedded in the substance employed. By these means the service is rendered practically everlasting at a very trifling cost.

The holes in the mains for services ought always to be drilled, and never cut with a gouge, as when drilled they are tapped with greater facility, while the operation is effected more readily and with less loss of gas than when the gouge is employed; further, there is not the after escape of gas which occurs with an imperfectly formed hole in the main.

A main of 2 inches diameter should never be tapped for a larger pipe than half-inch, otherwise it will be most materially weakened and will probably break with the slightest settlement or jar. For the same reason a 3-inch main may be tapped for a 1-inch pipe, but not larger; and in the event of the services being required of greater dimensions this can be effected by means of diminishing sockets, for a slight reduction in the diameter of the pipe for a very short distance will not impede the flow of gas through a service.

All service pipes should have a fall to the main if possible, but if this is not practicable, they should then fall in the reverse direction, what is known as a "bottle syphon" (fig. No. 30 on the Plate), being fixed at the lowest point for the reception of the condensed products. Bottle syphons are made of all sizes to contain from one to three quarts, and attached to each is the suction pipe for withdrawing the liquid. With every precaution, however, service pipes sometimes get choked either with water,

naphthalene, or rust, when it is necessary to resort to the force-pump in order to clear them.

The service pipes to all public lamps are usually of half-inch pipe unless when of considerable length, when they are laid of three-quarter inch pipe.

"If the distance from the main to the meter does not exceed 30 yards, the following sizes of service pipes will supply the number of lights named.

					Wrought-iron Tube.
" 1 to 10 lights (consuming say 4 cubic ft. per hour each)					$\frac{3}{4}$ inch.
11 to 30	"	"	"	"	1 "
31 to 60	"	"	"	"	1 $\frac{1}{4}$ "
61 to 120	"	"	"	"	1 $\frac{1}{2}$ "
121 to 200	"	"	"	"	2 "

"The above sizes allow for partial contraction of the area of the pipe by corrosion or deposition" (Newbigging).

It will be necessary at this stage to say a few words concerning the formation and deposition of naphthalene. Naphthalene, which is one of the hydrocarbons on which the luminosity of coal-gas depends, although generally present in very small quantity, is sometimes exceedingly troublesome, especially when the gas is saturated with it, as in such a case any lowering of temperature causes it to be deposited in the solid form in the apparatus and mains on the gas-works, and in the mains and services on the district, sometimes choking up the service pipes, and reducing the capacity of the mains.

No question in the whole range of gas manufacture has probably been more debated than the subject of the formation and deposition of naphthalene, or with so little progress towards arriving at a definite conclusion.

Naphthalene is generally considered to be produced by employing high temperatures in the distillation of the coal, and is deposited most freely from gas produced from bituminous coal, some descriptions of coal, such as those

from the South Yorkshire and Durham districts, coals which yield on distillation thick tars and a considerable quantity of water, producing more naphthalene than others.

“By the use of a certain proportion of cannel along with the ordinary common coal, the gas is enabled to retain some or the whole of the naphthalene in suspension within it in the gaseous condition” (Newbigging).

Mr. L. T. Wright's remarks on this subject will be of interest: “It seemed as if water vapour in the retort had some protective action on this hydrocarbon. Any coal could be distilled at such a low temperature that no naphthalene would appear, but when the heat was increased this substance made itself manifest, and after certain temperatures were reached it increased more and more. The question of dealing with gas saturated with naphthalene was sometimes very difficult. If one could always insure that the gas should be made and treated in the works at a lower temperature than it would ever be subjected to in its after history, there would be no trouble, but it would often happen that gas was made during the hottest part of the day, and purified and dealt with at temperatures much higher than it was submitted to in the mains and services during the night. As a rule, naphthalene only showed itself in mains and services laid within a foot of the surface of the ground, those buried deeper than this undergoing no appreciable variation in temperature. The cure for this evil would consist in some method of artificially cooling the gas before it left the works.”

M. Brèmond, who made some valuable researches on the question of the formation of naphthalene, published his results in the year 1877, and then stated that “Naphthalene is produced wherever there is condensation of the aqueous vapours contained in the gas; that its deposition is preceded by the phenomenon of the condensation of the

water, and that gas absolutely deprived, as far as possible, of aqueous vapour does not deposit naphthalene under the ordinary conditions of temperature and pressure."

Friction, even when the gas is at ordinary temperatures, is one of the causes of the deposition of naphthalene, while sudden changes of temperature intensifies the evil. It has frequently been noticed that condensation of naphthalene, and its deposition as crystals in the pipes, are promoted by and usually occur where there is any roughness or burr on the inner surface of the pipe, on the well-known principle that crystallization is promoted by the presence of a solid body in a crystallizable liquid, or to a lesser extent where there is a sharp bend in the pipes, which, by producing friction on the gas, acts somewhat in the same manner as a burr or roughness; further, most of all the deposit occurs at places where the gas is subjected to a sudden lowering of temperature.

The circumstances under which a deposit of naphthalene most frequently takes place are when the pipes are subjected to great atmospheric changes, or when a pipe passes into and out of the ground. As instances of the first class, we may cite the effect of a shower of rain in summer or of a frost in winter upon the street lamps, and also the frequent stoppages which take place in pipes which are led across bridges, and which are usually exposed or inadequately protected from the action of the atmosphere. As an instance of the second class, the following remarks of Mr. G. Anderson will serve as a typical illustration:

"In one case which came under my notice the inlet of a gas-holder was filled with naphthalene. The inlet pipe went down into the ground, and at a certain level (about ten feet under ground) there was water in the soil. When the cap was taken off, in order to 'plunge' the pipe, it was found that the deposition commenced *exactly at the water's edge*, and that down to that point the pipe was clean."

From the foregoing it will be seen how necessary it is to have all pipes free from burrs and projections, and in laying mains to avoid sharp turns and angles. Further, it is an advantage to protect the exposed parts of mains and service-pipes, especially the pipes in the works at the points where they pass into wet soil, as at the outlets and inlets of gasholders, and wherever else the pipes pass from one medium into another which is colder. At such points, as also where the pipes are led across bridges, it will be found highly advantageous to jacket the pipes, or surround them with cheap non-conducting material.

Naphthalene deposits may be cleared from service pipes by means of the force-pump, or by pouring naphtha into them, naphthalene being soluble in naphtha.

CHAPTER XVII.

THE CONSTRUCTION OF GAS METERS.

TH**ERE** are two kinds of gas meters in use, the "wet" meter and the "dry" meter. The former derives its name from the fact that it requires a quantity of water in order to work it, while the latter works without water, being complete in itself. Both descriptions of meter are employed for the registration of gas on consumers' premises; but the gas made on the works is always registered by a "wet" meter, known as the Station Meter.

The wet meter may be said to consist of a cast-iron outer case containing a cylindrical vessel of tinned iron, known as the measuring-wheel or drum, which is capable of freely revolving upon an axle or shaft in a horizontal position in suitable bearings. The drum is immersed in water, which fills the outer case to a predetermined level. It is of different diameters, according to the size of the meter, and is divided into four longitudinal compartments, arranged somewhat in the form of four blades of an Archimedean screw, the inlet end being isolated from the outlet side of the drum by the contrivance known as "the spout

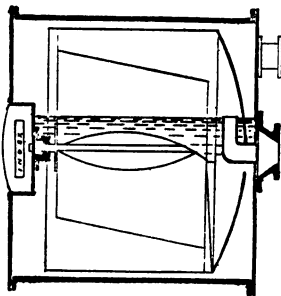


FIG. 53.

and hollow cover," shown in fig. 53, which is a section of a wet station meter; from which it will be seen that the gas enters at one end of the drum and leaves it at the other, but, by reason of the manner in which the partitions are arranged, there is not a clear way through the drum, the opening at one end of a chamber being above the water-line at the same time that the corresponding opening at the other end is below it. Two of the compartments are constantly above the water-line, the one filling with gas, the other discharging.

The openings at each end of the chambers through which the gas passes are long narrow passages, shown in section in the figure, and in elevation, are of a triangular form, and are known as "hoods." The gas entering the measuring drum presses against the under-side of the longitudinal division, and turns the drum round for a quarter of a revolution, expelling in the process the gas contained in that chamber which has immediately preceded it, and so on. Each chamber in rotation, as it fills with gas, turns the drum round a quarter of a revolution, and expels the gas from the chamber which precedes it.

The cubical space in each chamber when out of the water and full of gas is known. Four times this space represents the available capacity of the drum, and, consequently, the quantity of gas that has been contained by it in each revolution.

The spindle or shaft of the drum is in connection with a train of wheels, the latter being provided with pointers, which traverse the meter dials, and in this way the number of revolutions made by the drum is recorded, and, consequently, the amount of gas which has passed through the instrument is correctly registered. Fig. 54 is a section of a meter, direct through the centre of the drum.

The superiority claimed for wet over dry meters as accurate measurers of gas, lies in the fact that for a flexible

measuring chamber one of rigid construction is substituted, and for dry slide-valves, the hydraulic seals of the drum partition, from which it will be seen that the accuracy of the registration of the wet meter largely depends upon maintaining the water in the meter at the correct level; for if the water-line be low, the available gas space in the measuring drum will be more than it should be, and the meter will register slow, *i.e.*, it will register a smaller quantity of gas than that which has actually passed through, while if the water line is high, the gas space in the measuring drum will be correspondingly reduced, and the meter will register a quantity of gas in excess of that actually passed through. In this case the meter will register fast. The best way of maintaining a constant water level is to place the outlet of the water overflow pipe at the proper level, and then to have a small stream of water constantly flowing into the meter, but this method of regulating the water level is only applicable to station meters.

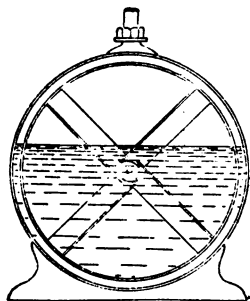


FIG. 54.

In order to insure the water-line of consumers' meters being always maintained at the proper level, various devices have been introduced under the name of compensating meters. Most meters of this class have a reservoir of water within the meter case, the water being distinct from that in which the measuring drum revolves; this reservoir of water serves to compensate for any diminution of water in the body of the meter by evaporation, or otherwise; the water is transferred to the body of the meter by various automatic contrivances, such as by the agency of spoons, scoops, etc., which, being connected to the spindle of the

meter, revolve with the same and transfer the water as already described.

The Sanders and Donovan meter is provided with a compensating hollow metallic float, accurately balanced on pivots within the front portion of the meter case, and

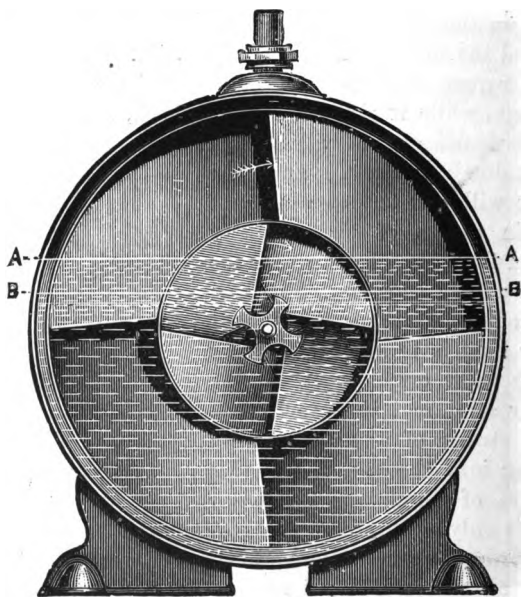


FIG. 55.

independent of the action of the instrument; the action of this arrangement is exceedingly simple, for, according as water is added to or withdrawn from the meter, the float rises or sinks in proportion, thus always maintaining a constant water level.

The most accurate method of insuring a constant water-line in the consumers' meters, however, is by the employ-

ment of the Warner and Cowan patent drum, whereby the drum itself is so constructed as to automatically correct its registration for any fluctuation in water level. This result is brought about by forming a second and smaller drum concentric with the larger one, but having its partitions placed in the opposite direction. Its capacity is such that

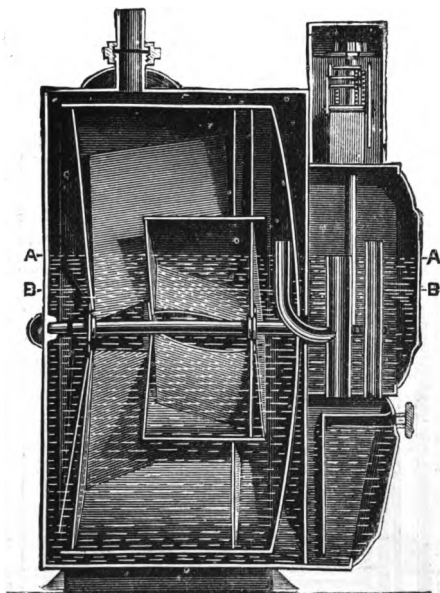


FIG. 56.

the exact excess of gas passed beyond what is *registered* with any water level below the true one, is returned by it to the inlet to be re-measured.

Meters constructed upon this principle register exactly the quantity of gas flowing through them under all variations of water level. Figs. 55, 56, show the Warner and Cowan drum as just explained.

The dry meter is shown in figs. Nos. 57, 58, 59, as manufactured by Messrs. Cowan and Co., of West-

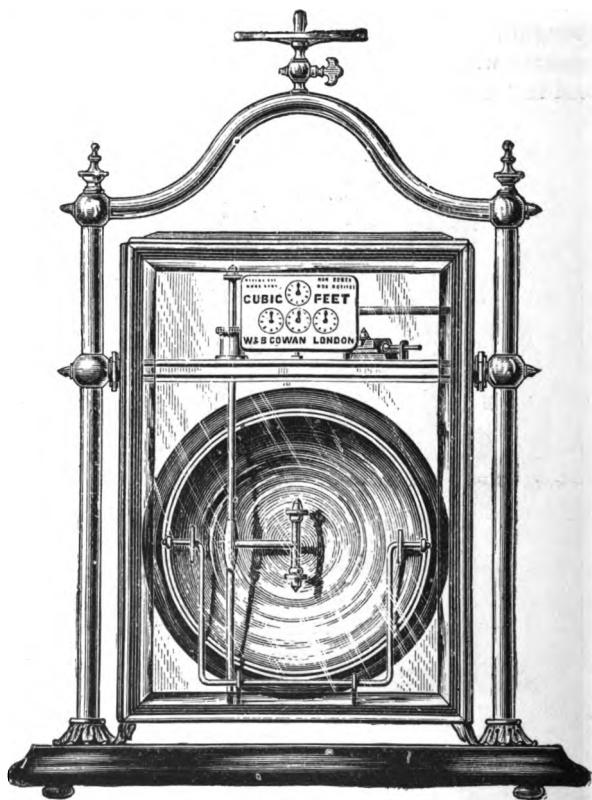


FIG. 57.

minster. The instrument consists of an outer case which is divided by a horizontal partition into two compartments, the upper one containing the valves which convey the gas into and from the respective measuring chambers; the

lower compartment is subdivided by the vertical partition shown in the side view, to which are attached two flexible chambers. There are thus formed four distinct chambers viz., the interior of the flexible chambers, and their exteriors, or in other words, the spaces the flexible chambers move through, all being in communication with their respective ports of the slide valves described later on.

Each of the flexible chambers is formed by a large disc supported and guided by what is known as a "flag piece" and guide, which allow it to pass with freedom through the desired distance, and keep it always in the same plane. A flexible leather band hermetically secured to the disc as well as to a ring soldered to the central partition completes the flexible chamber.

The gas on entering one of the flexible chambers expels an equal quantity of gas from the outer chamber to the burners, and when the disc passes through a certain distance, the position of the valve is changed. The action is then reversed, the gas now entering the outer chamber and expelling a like quantity from the interior of the "bellows." The reciprocating motion given to the disc as the chambers inflate and collapse is conveyed to the valves through what are called "tangent arms," which are attached to another arm

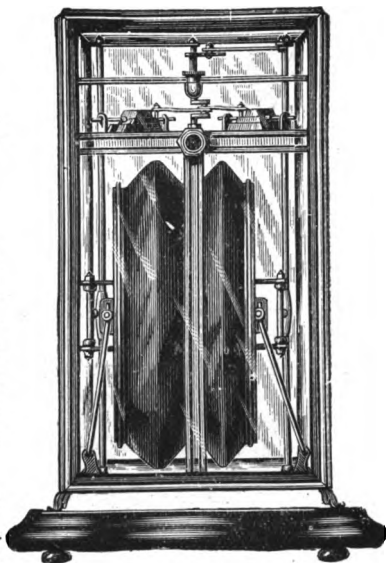


FIG. 53.

fixed to the crank and called the "tangent" in the upper or valve chamber, and by means of suitable gearing works the valves, and also causes the index wheels to revolve. The valves fig. 59, are placed over each measuring chamber, and are similar to the slide valves of a steam-engine, having three ports which communicate with the inside and outside of the measuring chambers and the meter outlet.

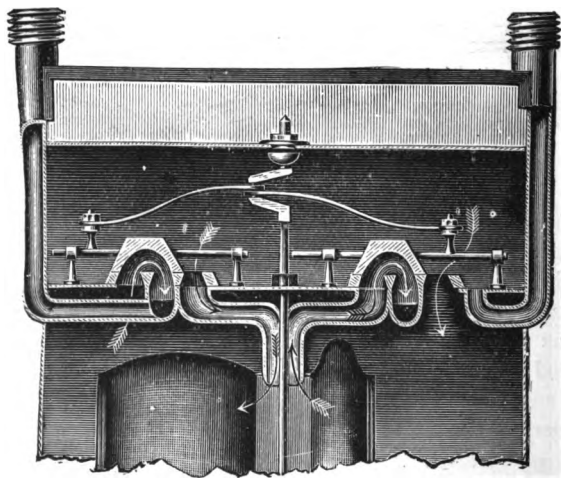


FIG. 59.

The action of the instrument is briefly as follows:—The gas on entering one of the flexible chambers, say No. 2, the disc will be caused to move through a certain distance expelling a like quantity of gas from chamber No. 4 equal to that entering chamber 2, and when the diaphragm is distended to the required degree, the position of the cover of the valve is changed. The gas then enters chamber No. 3, expelling that from No. 1 until the disc nearly touches the ring, when the flexible chamber will be collapsed,

and the position of the valve cover is changed. The gas enters the chambers in succession, receiving and expelling continuously so long as any supply from the instrument is required. The complete action of distention and collapse is transmitted to the index as previously described, and the gearing of the index is arranged according to the capacity of the chamber when fully inflated.

PENNY IN THE SLOT METERS. PREPAYMENT GAS METERS.

A considerable impetus has within the last few years been given to the consumption of gas by the invention of the penny in the slot prepayment meter.

Gas is probably one of the most important of the many commodities for the delivery of which automatic mechanism has been devised.

The system, as applied to gas, is not only useful to the public, but it also secures to gas companies and corporations a new source of revenue free from the risk of bad debts. In the United Kingdom alone there are hundreds of thousands of householders who do not burn gas, and of these a large proportion, especially in manufacturing centres, purchase their light, whether oil or candles, in small quantities, and cannot be persuaded to adopt gas because of their disinclination or inability to meet the payment of periodical gas bills. The prepayment system, in which penny in the slot prepayment meters are employed, entirely removes this difficulty because it enables the consumer to purchase at pleasure a pennyworth of gas just as he would buy oil to the same value.

When once such a meter is fixed in a house it generally remains there permanently, no matter how many changes of tenancy may occur, or how often; as each successive tenant who finds such a convenient meter in his home

readily takes to the idea and patronizes the penny in the slot meter instead of the oil seller. Of the many penny in



FIG. 60

the slot meters in the market, those of Messrs. Cowan and Co. enjoy a well deserved reputation. Messrs. Cowan's

meters are constructed on the most reliable and approved principles, and give every satisfaction both to the consumer and to the gas company.

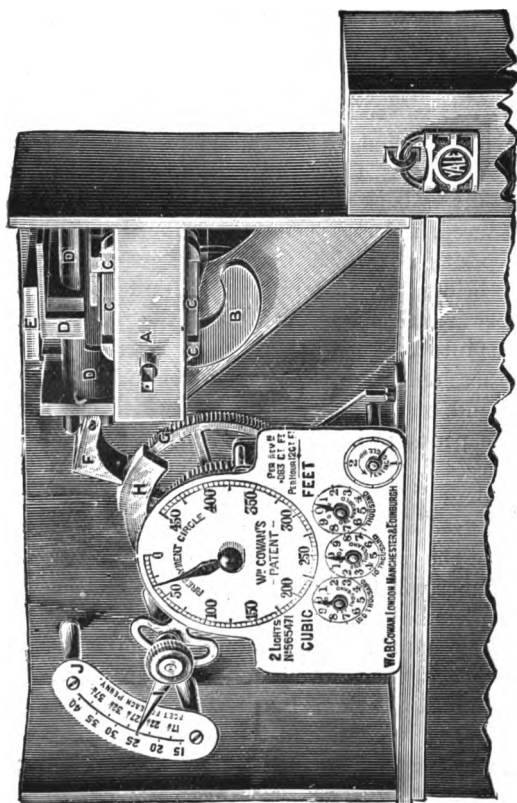


FIG. 61.

A distinctive feature of these meters is the price-adjusting mechanism by means of which the gas company's inspector can readily adapt the meter *in situ* to a change

in the price of gas by altering the position of a pointer on a graduated scale which is under seal.

Fig. 60 shows one of Messrs. Cowan's dry meters with penny in the slot attachment, and fig. 61 the mechanism of the same, of which the following is a description :

"By turning to the right the handle fixed on the shaft *A*, the cam *B* presses against the left-hand bearing of box *C*, by which it is moved forward with the pusher attached to it. If the movement of the handle be continued, the cam next presses against the right-hand bearing of the box *C*, and thus draws back the pusher. No other effect is however produced, unless a penny is dropped into the slot *E*, the interposition of which between the pusher and the coin carrier *D* brings the latter into action, and carries the pawl *F* first forward, then backward, when the penny is released and drops into the cash box.

"By these operations the prepayment wheel *G* is moved partly round, and the number of feet which has been paid for by the penny is indicated by the long pointer on the dial. Successive pennies may, if convenient, be put in, but no more than 450 feet of gas can be prepaid at one time.

"A pin fixed at the back of the wheel *G* closes a valve on the inlet of the meter when the long pointer reaches zero. The consumer will have due warning before the supply of gas which has been paid for is exhausted, as the valve will gradually close during the consumption of the last five feet.

"The wheel *G*, when moved round by the pawl *F*, is released from the index gearing, but resumes contact therewith when the pawl recedes, and thus records in concert with the ordinary index the quantity of gas passed through the meter.

"*Price Changing.*—It will be obvious that with coin meters provision must be made whereby the mechanism can be adjusted easily and *in situ* to meet changes in the price of gas.

“The extent of the movement given to the prepayment wheel *g* by the pawl depends on how much of the ‘travel’ of the pawl is allowed to operate on the wheel. The price-adjustment platform *h* (the position of which is determined by the setting of the pointer *i* in relation to the scale *j*) supports the pawl off the teeth of the wheel during more or less of the movement the pawl has. If, therefore, the adjustment platform be well forward, the movement of the pawl will produce comparatively little effect on the wheel; but if the platform be so placed that the pawl almost immediately gears into the wheel, the wheel’s movement will in that case be almost equal to that of the pawl. The pointer *i* moves and fixes the platform, whilst the scale determines the position in which the pointer is to be fixed, and this is made to suit the price of gas in operation at the time.”

THE STATION METER.

The Station Meter, as its name implies, is employed to register the amount of gas produced on the works, and is always of the “wet” description. It is in principle the same as the consumer’s wet meter, although differing from the latter in a few minor details of construction.

Station meters of small dimensions are generally cylindrical; those of a larger capacity are usually made square, and frequently the outer case is very ornamental. The inlet and outlet pipes of station meters are at the back of the instrument, the inlet pipe being in the centre. The index dial is fixed in the front in the centre; the float which regulates the water-line in a consumer’s meter is not employed, the water-line being indicated by a glass gauge fixed outside the instrument.

The capacity of a station meter for a works of a given size is governed by the maximum make of gas per hour, and it is requisite to see that the speed of the drum does

not exceed 120 revolutions per hour, as when the drum revolves at a greater speed than that mentioned, extra pressure is required to work the meter, while the increased pressure causes the water to become depressed in the measuring chambers of the drum, which causes their capacity to be increased, with the result that the meter registers slow.

The gas registered is indicated on a series of enamelled dials, the pointers attached to which indicate from 100 to 100,000,000 cubic feet at each of their revolutions. These dial figures differ from those attached to a consumer's meter, inasmuch as they all run in the same direction. Attached to the index of large meters is an eight day clock, the hour hand of which is connected with a rod carrying a pencil actuated by a slight spring. On a circular plate a graduated card is fixed, and the lead pencil attached to the clock presses upon the card, and thus indicates the amount of gas produced during any part of the twenty-four hours.

Station meters should be fixed perfectly level on a solid foundation, and be provided with inlet, outlet, and bye-pass valves, adjustable overflow pipe, water gauge, an ordinary pressure gauge for both the inlet and outlet pipes, and also a differential pressure gauge.

The water-level of the station meter should always be maintained at the same height as indicated by the water gauge, by allowing a small stream of water to constantly flow into and from it.

CHAPTER XVIII.

GAS BURNERS.

THE burners in general use for illuminating purposes may be divided into the following classes: flat-flames, argand, regenerative, and incandescent; but before proceeding to describe these different varieties, it will be necessary to say a few words concerning the principles of combustion on which the amount of light emitted from burners of the flat-flame, argand, and regenerative type depends.

At the outset it may be stated that the luminosity of a gas flame such as those above-mentioned is due to the presence of carbon particles which are heated by the high temperature of the flame to incandescence. When a gas such as coal-gas, consisting of a mixture of gaseous compounds containing carbon and hydrogen is ignited in contact with a regulated supply of air, the hydrogen of the hydrocarbon is the first to unite with the oxygen of the air by reason of its great affinity for the latter element. Under these conditions the carbon with which the hydrogen was previously combined is for the moment liberated in the free state in the interior of the flame, and, becoming intensely ignited, gives rise to a development of light, the carbon particles passing subsequently to the exterior of the flame, where there is a comparative excess of air, becoming completely burnt to CO_2 .

The ultimate products of combustion, therefore, being

water derived from the hydrogen of the hydrocarbon, and CO_2 from the carbon of the same.

When gas is burned with an insufficient supply of air, the flame becomes larger than it would normally be, and of a yellowish colour, owing to the carbon particles not being heated to the degree of incandescence which is necessary for the production of a *white* light, this being the result of incomplete combustion, as, instead of the carbon being entirely consumed, a large proportion passes off in the form of smoke.

On the other hand, when gas is consumed in contact with a proportion of air greater than that which is requisite for the full development of its light-giving constituents, the flame shortens, with a corresponding decrease of luminosity, and if the air be largely in excess, then the flame loses, to a greater or less extent, its white appearance, and assumes a bluish tint. Under these conditions the amount of air supplied to the flame is largely in excess of that required for the complete combustion of the hydrogen, and the excess of oxygen present unites immediately with its proportion of carbon, which, being burned direct, does not produce light. It follows from the foregoing, therefore, that one of the conditions necessary in order to develop the greatest possible amount of illuminating value from gas, is to adjust the amount of air supplied to the flame to the amount of carbon and hydrogen in the gas.

The methods of regulating the quantity of air supplied to a flame differ according to the description of burner. In the batswing and fishtail the size and angle of the apertures determine the amount of air, while in the Argand the chief regulating agency is the chimney by which the amount of air admitted is under complete control. With a poor gas a comparatively small amount of oxygen in the form of air is required, and the most suitable burners for consuming gas of this description are those with compara-

tively large holes. The directive force with which the gas issues is small in proportion to the quantity passing, and as a consequence the supply of air is likewise correspondingly small.

With a rich gas, considerably more oxygen is required, and the most suitable burners for such gas are those having comparatively fine apertures, whereby the directive force of the gas is increased, and with it the amount of oxygen. Another point to be attended to in the construction of gas burners is, that the material composing the burner should be a non-conductor of heat, such as steatite, and thus keep the flame hot, as, if a material which is a conductor of heat, such as iron, be employed, this robs the burner of its heat, and lessens the intensity of combustion.

The conditions to be arrived at in the construction of a good gas-burner are, therefore, to have the burner of a non-conducting material, and to regulate the amount of air admitted to the burner according to the quality of the gas. The amount of air admitted to the burner, and the cooling of the flame, are largely influenced by the pressure at which the gas issues from the burner, for if the pressure is greater than that for which the burner is constructed, a roaring flame results, with a consequent loss of illuminating power, as the too rapid rush of gas from the burner causes a mingling of gas and air, and a consequent cooling of the flame, while the form of the flame becomes distorted. On the other hand, in flat-flame burners, the pressure at which the gas issues from the burner fulfils the important function of promoting intensity of combustion, by bringing the white-hot particles of carbon into intimate and rapid contact with the air that is necessary for complete combustion. In Argand burners this duty is discharged by the glass chimney, but with flat-flame burners it devolves entirely upon the pressure at which the gas

issues from the burner. The effect of pressure on gas flames may briefly, then, be said to be that with an excessive pressure the intensity of combustion is increased, but the separated carbon does not remain so long in the flame. As a consequence, the area of luminosity is decreased, and the total amount of light yielded is reduced. On the other hand, with an insufficient pressure, the combustion is not energetic enough to raise the carbon particles to a proper degree of incandescence, consequently the flame possesses a very feeble illuminating power, or else the carbon escapes unconsumed in the form of smoke.

The most common defect is that of excess of pressure, and various devices have been introduced from time to time, in order to secure an uniform pressure at the burner. Flat-flame burners embrace the fishtail and batwing.

The union jet, or fishtail burner, derives its name from the shape assumed by the flame, which has some resemblance to the tail of a fish. The gas issues through two apertures, inclined at such an angle that the two currents of gas impinge against each other and spread out laterally, giving a flame at right angles to the point of exit. The diameter of these orifices varies in different burners, so as to produce flames of thickness suited to the quality of the gas they are intended to consume, as with flat-flame burners the thickness of the flame is the great factor in the utility of the burner. Fishtail burners are usually constructed of brass, while the top of the burner from which the gas issues is made of steatite, or other non-conducting material. In some burners of this type the hollow chamber of the burner is plugged with cotton-wool, or small discs of fine wire gauze, the object being to lessen the pressure with which the gas issues from the burner apertures.

The batwing burner has a hollow dome-shaped top, across which a narrow slit is cut. The dome being of

equal thickness throughout, it follows that the slit is of equal depth throughout its length, so that the gas issues with equal force from every portion of the slit. The slit varies in width to suit various qualities of gas.

A batwing burner requires less pressure than a fish-tail, and consequently the gas issues with less directive force, and the flame is not so stiff as with a fishtail; it is consequently necessary to protect it from draughts, which in the case of Sugg's table-top burner is effected by providing the burner with a rim just below the tip. The large batwing burners, which are used in street lighting, are provided with side wings or lugs for the same purpose. As previously remarked, some flat-flame burners are provided with means for checking the pressure of gas, but the ordinary means of effecting this object, viz., by the plugging of the burner case with cotton-wool or other material, is not to be commended. On the other hand, the burners manufactured by Mr. George Bray, of Leeds, and known as Bray's "Special" burner, are so constructed that they fulfil this object admirably.

In this description of burner a piece of enamel is introduced into the lower part of the burner case, pierced by a small circular hole for the admission of gas into the burner, the diameter of this hole determining the quantity of gas which at any particular pressure is admitted into the burner.

Placed just above the enamel washer is a layer of muslin, for the purpose of lessening the "swirl" which is given to the current of gas by passing through the narrow opening in the enamel. These burners are designed so as to enable the gas to be consumed at the lowest pressure which will maintain a firm flame, and with the least amount of swirl in the gas current as it issues from the burner. The former object is attained by diminishing the area of the opening which admits gas to the burner,

without a corresponding decrease of the orifices through which the gas issues into the atmosphere, and the latter by interposing the layer of muslin which is immediately above the diminishing arrangement, and also by the enlargement of the gas chamber in the upper part of the burner.

The Argand burner is shown in fig. 62, and may be said to consist of an annular steatite ring or chamber, provided with a series of tubes or connections for communicating between the interior of the chamber and the gas supply, and perforated on its upper surface with a number of holes for the emission of the gas. Through these holes the gas issues in a series of jets, which immediately coalesce, to form one cylindrical sheet of flame. The burner is surmounted and the flame enclosed by a glass chimney, which is supported on a light gallery connected with the lower portion of the burner, which is made of brass. The chimney serves the double purpose of shielding the flame from air currents, and of drawing upon the surface of the flame the supply of air necessary for its proper and complete combustion; and this is further assisted by placing between the chimney and the burner orifices a small metallic cone, which directs the air supply upon the surface of the flame.

The combined sectional area of the three tubes which supply the gas to the annular chamber is less than the aggregate area of the burner orifices from which the gas issues, so that the gas is delivered from the latter at a considerably less pressure than that at which it enters the burner.

It is necessary to note that in the Argand type of burner the air supply is produced under conditions totally different from those which govern its production in the case of flat-flame burners. In flat-flame burners the quantity of air supplied to the flame is determined by the pressure of the

gas, or, in other words, the velocity with which it issues from the burner. In Argand burners, on the contrary, the air supply is obtained quite independently of the pressure at which the gas issues; and the conditions most effective for the economical combustion of the gas, and the development from it of the highest illuminating power attainable, are only secured when the pressure of gas is reduced to a minimum.

Within the last few years various attempts have been made to develop more illuminating power from a given quantity of gas than was capable of being obtained from the burners of the Argand and flat-flame type. These attempts have resulted in the introduction of the so-called Regenerative "burners," and the Incandescent gas-burner known as the Welsbach, from the last-mentioned of which Gas Companies will undoubtedly reap enormous advantages.

The so-called Regenerative burners utilize the waste products of combustion from the gas-flame to raise the temperature of the gas before it is ignited, and likewise of the air necessary for its combustion; and it is by the adoption of this principle that the results yielded by the use of burners of this type are obtained. The effect of heating the gas and air before combustion may be briefly said to be the liberation of the carbon particle at an early stage in the flame; the raising of such particles to a higher temperature than is possible with the ordinary form of burner, and also that such particles are kept in the incandescent condition for a longer period.

There are various descriptions of regenerative burners in use, amongst the most popular being those of Mr. Sugg, known as the "Cromartie" and the "Wenham." In the

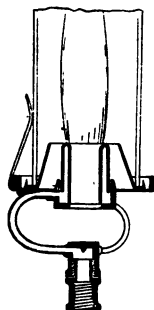


FIG. 62.

latter form of burner the flame, which is circular, somewhat resembling an inverted Argand, is deflected by a plate of porcelain, and passes upwards towards the interior of the burner, the gas and air supplying the same being contained in separate pipes, which are heated by the products of combustion and the flame itself in the chamber below, from which any other air is prevented from having access by means of an air-tight glass shade which surrounds the flame.

Fig. 63 shows a section of the Wenham lamp; *A* is the air-inlet, *B*, the regenerator, which is made of iron, and serves to absorb the heat of the gas-flame burning beneath it, and to communicate it to the incoming air. A cylinder, *C*, conveys the heated air to the burner through the perforated discs; *D* is the burner; *E*, the flame; *F*, the reflector; *G*, the fastener of the ring, *J*, which carries the lamp-glass, *K*, and has a hinge at *H*; *L* is the chimney; *M*, the gas supply; and *N*, the heat disperser.

The following table, by Professor Lewes, shows the amount of light obtained from burners of different types:

Burner.	Light obtained per cubic feet of 16- candle gas consumed. Candle units.	
Regenerative	10.00	
Standard Argand	3.20	
Ordinary Argand	2.90	
Flat flame, No. 7	2.44	
„ No. 6	2.15	
„ No. 5	1.87	
„ No. 4	1.74	
„ No. 3	1.63	
„ No. 2	1.22	
„ No. 1	0.85	
„ No. 0	0.59	

The most notable advance, however, in the means for developing the maximum amount of light obtainable from

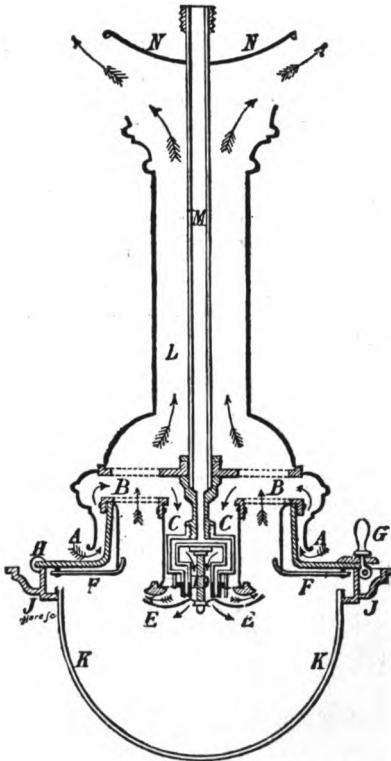


FIG. 63.

coal-gas is by the employment of the incandescent gas-burner of Dr. Welsbach.

In this system, what is known as a cone or "mantle" of incombustible material is dipped in a solution of the rare

earths, thoria and cerium, which have the property, when highly heated, of emitting a most powerful light.

This mantle is placed over an atmospheric, or Bunsen, burner, with the result that a magnificent white light is produced with the consumption of an almost infinitesimal amount of gas, a light of 70 candles being obtainable from $3\frac{3}{4}$ cubic feet of ordinary 16-candle gas; together with the further advantage that it only yields from one-half to one-fifth the amount of heat which attends other systems of gas-lighting. In this burner gas companies possess the most powerful weapon they have ever had placed in their hands with which to fight the electric light, as the light yielded by the incandescent burner as applied to domestic purposes is quite as powerful, and the cost is very much less.

CHAPTER XIX.

INFLUENCE OF TEMPERATURE AND PRESSURE UPON THE VOLUME OF GAS.

THE distinguishing property of gases is their power of indefinite expansion when subjected to changes of temperature and pressure, with a corresponding change in volume; it is consequently necessary to make corrections for such changes in volume by reducing the volume of a gas under a given temperature and pressure to some common standard, which, in the case of coal-gas, is the temperature of 60° F., and a barometrical pressure of 30 inches of mercury.

These corrections are based on the following physical laws:

1st, for pressure.

By the law of Boyle or Mariotte, "the volume of a given mass of any gas varies inversely, as the pressure; the temperature being constant, calling volume V , and pressure P , the volume of $V P$ is constant."

Thus, if V is the volume, when the pressure is P the volume of the gas becomes:

	$\frac{1}{2} V$	when the pressure is	.	.	$2 P,$
	$\frac{1}{3} V$	" "	.	.	$3 P,$
	$\frac{1}{4} V$	" "	.	.	$4 P,$
Also	$2 V$	" "	.	.	$\frac{1}{2} P,$
	$3 V$	" "	.	.	$\frac{1}{3} P.$

Or, expressed in words, doubling the pressure reduces the

volume to one-half, and, conversely, reducing the pressure one-half doubles the volume.

Now, supposing we measured 1,000 cubic feet of gas under a barometrical pressure of 30·6 inches, and we wished to know what it would measure at 30 inches; as the pressure under which the gas is measured is *greater* than the standard pressure (30 inches), it is plain that under the latter pressure the volume would be greater, we therefore say:

As 30 : 30·6 :: 1,000 : x , $x = 1,019\cdot3$ cubic feet.

Or, supposing that we measured 1,000 cubic feet of gas under a pressure of 29·5 inches, and we wished to know the volume at the standard pressure, in this case the gas is measured under a lesser pressure than the standard; consequently, when reduced to the latter pressure, the volume would be reduced; in this case, therefore, we say:

As 30 : 29·5 :: 1,000 : x , $x = 983\cdot3$ cubic feet.

It will be noticed that in each case the standard pressure (30 inches) is in the first term.

2nd, for temperature.

As a general rule, bodies tend to expand when their temperatures are raised, and to contract when the temperature is lowered, gases being the most expansible of all bodies.

The law of change of volume with change of temperature is known as that of Charles and Gay Lussac, and may be stated thus:

“The volume of a gas under constant pressure expands when raised from the freezing to the boiling temperature by the same fraction of itself, whatever be the nature of the gas.”

It has been found by able experimenters that a volume of air at constant pressure expands from 1 to 1·3665

between 0° C. and 100° C., and all perfect gases expand in the same proportion.

Consequently, for every increase in temperature of 1° C., a gas expands by $\frac{1}{273}$ of its volume at 0° C., and for every rise of 1° F., a gas expands by $\frac{1}{459}$ of its volume at 32° F.

This fraction $\frac{1}{459}$ is called the co-efficient of expansion, and represents the increment or decrement which occurs in a measured volume of gas for every change of temperature of 1° F., provided the pressure remains unchanged.

Thus, 492 volumes of gas at	.	.	32° F.
Become 493	"	"	33° "
" 494	"	"	34° "
" 495	"	"	35° "
Also 492	"	"	32° "
Become 491	"	"	31° "
" 490	"	"	30° "

Now, supposing we measure 1,000 cubic feet of gas at a temperature of 80° F., and we wish to correct it to the standard temperature of 60° F. (the pressure remaining constant), 492 volumes at 32° F. become $492 + (60 - 32 = 28) = 520$ volumes at 60° F., and $492 + (80 - 32 = 48) = 540$ volumes at 80° F. The volume, therefore, of any gas at 80° F. would bear the same ratio to the volume which it would occupy at 60° F., as 540 does to 520, consequently,

$$\text{As } 540 : 520 :: 1,000 : x, \quad x = 962.9 \text{ cubic feet.}$$

If the gas, instead of being measured at 80° F., had been measured at 50° F., then, as before, 492 volumes at 32° F. would become 520 volumes at 60° F., and 492 volumes at 32° F. would become $492 + (50 - 32 = 18) = 510$ volumes at 50° F. Then the ratio to the volume at 60° F. would be obtained as follows:

$$\text{As } 510 : 520 :: 1,000 : x, \quad x = 1,019.6 \text{ cubic feet.}$$

It will be noticed that 520 always occupies the second term in the proportion. Now, in practice, the volume of a gas is always corrected for temperature and pressure at one operation, by combining the two corrections together, but the method of performing the necessary calculations will be better understood by a brief description of the "air thermometer," which has played a very important part in "thermo-dynamics, and has very much simplified the formula for adjusting volumes of gas under various conditions of temperature and pressure to standard.

"The air thermometer is a tube of uniform bore, sealed at one end, and containing a column of dry air disconnected from the outer atmosphere by a short column of mercury, which moves freely with the changes of the contained air.

"We will suppose the pressure on the column of air to remain constant during the following changes.

"Conceive the air thermometer immersed in a mixture maintained at 32° F., and the volume of the contained air to measure 1; then conceive the thermometer immersed in steam from water boiling under standard conditions, and, according to Regnault, the volume should now measure 1.3665, but probably 1.366. I adopt this figure in preference to the former. The problem now is:—Taking freezing point at 32° F. (1), and boiling point at 212° F. (1.366), find the temperature expressed at the bottom of the tube by continuing the Fahrenheit scale to that point. A simple calculation will show that it would be - 460° F. Let us shift the zero to the bottom of the tube and scale upwards on the Fahrenheit system, and the freezing point will consequently be on the new scale, + 492.

"Temperature expressed on this scale is termed by scientific men absolute temperature.

"The rule, then, for converting ordinary readings on the

Fahrenheit scale to absolute temperature in Fahrenheit degrees is to add 460°.

"The object now to be attained is to condense the laws of Boyle and Charles into one simple expression.

"Clerk-Maxwell neatly combines them in the following expression: 'The product of the volume and pressure of any gas is proportional to the absolute temperature.' Let V , P , T be the observed volume, pressure, and temperature on the absolute scale, and V° the volume at standard pressure P° , and standard temperature T° on absolute scale; then

$$\frac{VP}{T} = \frac{V^{\circ}P^{\circ}}{T^{\circ}} \quad (1)$$

$$V^{\circ} = V \frac{P}{P^{\circ}} \frac{T^{\circ}}{T} \quad (2)$$

$\frac{T^{\circ}}{P^{\circ}}$ is a constant quantity, and if the standard be 30 inches barometer and 520° thermometer, the standard absolute temperature becomes 17·333, and the formula for dry gases

$$\frac{VP}{T} 17\cdot333$$

But coal-gas is usually measured over water, and if it be considered necessary to correct for the varying pressure exerted by water vapour at various temperatures, we must slightly modify the above formula. The original formula can be used if it is understood that P represents the observed pressure, minus the tension exerted by water vapour at the temperature, T , and P° the standard pressure, minus ·5178, which is the tension of water vapour at the standard temperature, 520 (460 + 60).

"The Gas Referees' formula (preserving the symbols) is :

$$V^{\circ} = V \frac{P}{T} \frac{520}{30 - \cdot5178} = V \frac{P}{T} 17\cdot64."$$

(L. T. Wright.)

Or more simply, in order to correct a volume of dry gas to the normal temperature and pressure of 60° F. and 30·0" bar., multiply 17·338 by the observed pressure and then by the volume, and divide by the observed temperature + 460; or calling temperature T , pressure p , and volume V ,

$$\frac{17\cdot338 \times p \times V}{460 + t} = \text{corrected volume.}$$

In the case of a moist gas (Referees' formula), multiply 17·64 by the observed pressure, minus the tension of aqueous vapour at the observed temperature, then by the volume as before, and divide by 460 + t . The formula being

$$\frac{17\cdot64 \times (h - a) \times V}{460 + t}.$$

We will now describe how to utilize these two formulæ by an example showing the methods of correcting dry and moist gas respectively :

1,000 cubic feet of gas are measured at a temperature of 55° F., and under a pressure of 30·6 inches, what would it occupy at the standard temperature and pressure of 60° F. and 30·0"? Then

$$\frac{17\cdot33 \times 30\cdot6 \times 1,000}{460 + 55 = (515)} = 1029\cdot7 \text{ cubic feet.}$$

Now, supposing the same gas was measured in a moist condition, the calculation would then be

$$\frac{17\cdot64 \times (30\cdot6 - \cdot4329) \times 1000}{460 + 55 = (515)} = 1033 \text{ cubic feet,}$$

which agrees with the number given in the Gas Referees' table.

CHAPTER XX.

THE COMPOSITION OF COAL-GAS.

PURIFIED coal-gas is a mechanical mixture of hydrogen, carbonic oxide, and certain hydrocarbons, which are capable of existing as gases at ordinary temperatures; of these hydrocarbons marsh-gas figures prominently. There are also present certain hydrocarbons which occur in the gas in a state of vapour, and which, if isolated, would not be capable of existing in the gaseous form at ordinary temperatures. Nitrogen is also found in small quantities, and frequently oxygen is also present; but the presence of the latter gas is due to the drawing in, either accidentally or otherwise, of atmospheric air, as it is not produced by the distillation of the coal. There are also traces of sulphur and certain other compounds of a phenolic character.

The hydrocarbons upon which the luminosity of a coal gas flame entirely depend, are divided in the analysis of such gas into two groups—saturated and unsaturated—according to their behaviour with a solution of bromine in bromide of potassium, which has the power of absorbing the hydrocarbons termed “unsaturated,” but not affecting in diffused daylight the gaseous members of the saturated series of hydrocarbons; concentrated sulphuric acid acting in a similar manner to bromine.

Hydrocarbons are compounds containing carbon and hydrogen only, and they are divided into several series, in each of which the proportion of carbon to hydrogen bears

a definite ratio. Taking the letter C as representing twelve parts by weight of carbon, and H as denoting one part by weight of hydrogen, the hydrocarbon series present in coal gas may be represented as follows: n standing for the number of times twelve of carbon is found in the body.

(1) The paraffins— $C_n H_{2n} + 2$. Methane (or marsh-gas) and ethane may be taken as examples.

(2) The olefines— $C_n H_{2n}$.

(3) The acetylenes— $C_n H_{2n} - 2$.

(4) The benzenes— $C_n H_{2n} - 6$.

(5) Naphthalene— $C_n H_{2n} - 12$.

The paraffins constitute the saturated hydrocarbons present in coal-gas, and the term "saturated" is applied to them because they contain the maximum amount of hydrogen combined with the carbon.

In coal-gas the simplest member of the paraffin series, methane, is certainly one of the most important constituents, while minute traces of three other members of the same series are often present, viz., ethane, propane, and butane.

"Among the unsaturated hydrocarbons present in coal-gas, ethylene and benzene vapour play the most important part, while extremely small traces of propylene, butylene, acetylene, crotonylene, and naphthalene can be detected by working with very large volumes of gas. For all practical purposes we may look upon unenriched coal-gas as containing methane, ethylene, and benzene vapour, as the hydrocarbons which, during combustion, endow coal-gas flames with luminosity."

Ordinary 16 or 17-candle gas, made from caking coal, according to Mr. L. T. Wright, would have something like the following composition :

	Per cent.
Hydrocarbons capable of absorption, the exact formula not known ($C_n H_m$) .	4
Paraffins, treated as marsh-gas ($C H_4$) .	38
Carbonic oxide	6
Hydrogen	48 to 50
Nitrogen	2

Richer gases made from cannel coal generally contain a large proportion of the absorbable hydrocarbons, but a large percentage of these does not always mean great luminosity.

The following are recent analyses of coal-gas, as supplied by the three London companies serving the metropolis, as given by Professor Lewes:

Constituents.	South Metro- politan.	Gaslight and Coke.	Com- mercial.
Hydrogen	52.22	53.36	52.96
Unsaturated hydrocarbons	3.47	3.58	3.24
Saturated hydrocarbons	34.76	32.69	34.20
Carbon monoxide	4.23	7.05	4.75
Carbon dioxide	0.60	0.61	0.75
Nitrogen	4.23	2.50	5.10
Oxygen	0.49	0.21	0.00
	100.00	100.00	100.00

It will be necessary to briefly discuss some of the properties of these constituents.

The illuminating power of marsh-gas, when burnt in the standard Argand burner, is given by Mr. L. T. Wright as 5.2 candles per 5 cubic feet; but, according to Professor Lewis, a far higher illuminating value can be obtained from it at a higher temperature, i.e., when consumed in a regenerative burner, where it becomes nearly as luminous as

16-candle coal gas. A cubic foot of methane requires 2 cubic feet of oxygen, or 10 cubic feet of air, for its complete combustion, when it yields 1 cubic foot of CO_2 and 2 cubic feet of water vapour. Methane is present in coal-gas to the extent of from 30 to 40 per cent.

Ethylene has an illuminating power of 70 candles per 5 cubic feet, and requires for its combustion a larger proportion of oxygen than is the case with methane, 1 cubic foot of ethylene combining with 3 cubic feet of oxygen to form 2 cubic feet of CO_2 and 2 cubic feet of water vapour, and in order to obtain this quantity of oxygen, the combustion of a cubic foot of the gas will require 15 cubic feet of air. Benzene is an extremely volatile liquid, its vapour burning with a heavy red smoky flame. In arriving at its illuminating power, we have to see the effect produced by known quantities of benzene vapour diffused in combustible gases, such as hydrogen, as it is not possible to burn the pure liquid for the development of light even in lamps specially constructed for the purpose, as it is not possible to obtain a flame free from smoke. Drs. Frankland and Thorne determined its value in this manner, and found the illuminating power per 5 cubic feet of its vapour to be 420 candles. Knublauch gives its illuminating value as 820 candles.

A cubic foot of benzene vapour requires for its complete combustion $7\frac{1}{2}$ cubic feet of oxygen, or $37\frac{1}{2}$ cubic feet of air, yielding as the products of combustion 6 cubic feet of CO_2 and 3 cubic feet of water vapour.

"Another hydrocarbon which is present in only minute quantities in the coal-gas itself, but is developed in the changes taking place in the flame, and plays a very important part in causing luminosity, is acetylene (C_2H_2)."

Water at ordinary temperatures dissolves its own volume of the gas, and this is why it is present in such small quantities in coal-gas, as scrubbing and storage practically

remove it. One cubic foot of this gas requires $2\frac{1}{2}$ cubic feet of oxygen, or 12.5 cubic feet of air for its complete combustion, yielding 2 cubic feet of CO_2 and 1 cubic foot of water vapour. Its illuminating value has not yet been determined, owing to its solubility, but it has been observed to burn with a rich smoky flame.

The illuminating power of coal-gas is without doubt entirely due to the hydrocarbons just mentioned, and the prevalent idea entertained up to sixteen years ago was that the illuminating value depended upon the amount of ethylene, but this could not be the case, for, as shown by Professor Lewes, if it were true, 4 per cent. of ethylene, mixed with 96 per cent. of a combustible diluent, such as hydrogen, should give a 16 to 17-candle gas, whereas a mixture of 10 per cent. of ethylene and 90 per cent. of hydrogen has no luminosity. Barthelot concluded that the illuminating value of coal-gas was due to benzene vapour, but the opinion of Professor Lewes is (and anything originating from him is entitled to the greatest possible respect), that methane is one of the most important of the hydrocarbons present when the gas is burnt in such a way as to evolve from it its proper illuminating power, while the benzene vapour, small as the quantity is, comes next in importance, and the ethylene last. In the words of Professor Lewes, "it is the combined action of the hydrocarbons present which gives the effect, not any one of them acting alone."

We must now briefly discuss the properties of the "combustible diluents" which give volume to the gas, and produce a negative effect upon the light emitted by the flame. The most important of these is the hydrogen which constitutes about half the volume of ordinary coal-gas. Hydrogen burns in contact with oxygen, with a non-luminous but intensely hot flame. In burning it produces a greater heat than the same weight of any other substance known, 1 lb.

of hydrogen on combining with 8 lb. of oxygen giving out as much heat as will raise 34,462 lb. of water through 1 degree centigrade. A cubic foot of hydrogen when burnt combines with half a cubic foot of oxygen to form a cubic foot of aqueous vapour. Carbonic oxide, the other combustible diluent, exists in coal-gas to the extent of from three to eight per cent. The action of the diluents in coal-gas upon its illuminating power has been determined by taking ethylene with an illuminating power of 68·5 candles as a representative of the hydrocarbons, and diluting with the various constituents of coal-gas. Working in this way, Dr. Percy F. Frankland obtained the following results.

Combustible Constituents.

Diluent.	Percentage of ethylene.	Percentage of diluent.	Candle power per 5 cubic feet per hour.
Hydrogen . . .	77·55	22·45	54·58
	68·39	31·61	49·37
	53·58	46·42	39·21
	35·47	64·53	30·85
	26·08	73·92	22·84
	13·37	86·63	6·73
	10·00	90·00	0·00
Carbon monoxide .	81·65	18·35	55·27
	67·75	32·25	47·73
	46·30	53·70	33·09
	37·94	62·06	26·52
	28·73	71·27	13·26
	23·89	76·11	6·56
	20·00	80·00	0·00
Methane . . .	85·67	14·33	57·91
	69·09	30·91	47·88
	57·74	42·26	40·42
	35·90	64·10	33·17
	13·00	87·00	19·35
	6·87	92·13	17·59

"These results show that with the combustible constituents, hydrogen reduces the illuminating power least with large quantities of the hydrocarbons, but that methane is preferable when in excess, as with low percentages of the illuminant, especially when burnt at a high temperature, methane itself becomes an illuminating agent. This is due to the fact that although when methane burns at ordinary temperature it is non-luminous, at a high temperature some of it is broken up into acetylene, which gives it luminosity.

"Carbonic oxide is the most injurious of the combustible diluents, 80 per cent. mixed with ethylene rendering it non-luminous, a result which would require 90 per cent. of hydrogen.

"The constituents of an illuminating gas have a very great influence upon the size of a coal-gas flame. Both hydrogen and carbonic oxide burn with an extremely short flame, as they only require one-half their own volume of oxygen for their complete combustion, and are able to obtain this with a very short travel from the burner, while methane, requiring twice its volume of oxygen, burns with a flame nearly four times the height, if consumed at the same rate of flow. The percentage of ethylene, ethane, and benzene, in coal-gas is so small, that they can do but little towards increasing the size of the flame, although when pure ethylene or ethane is burnt alone it would not be possible to consume it in an ordinary burner at the rate of 5 cubic feet per hour. Using the London Argand as employed for gas testing, it would not be possible to burn much more than 2 cubic feet of pure ethylene or ethane per hour without the flame smoking. Using ordinary 16-candle London coal-gas enriched by cannel, it may be roughly stated to yield a 3-inch flame in the London Argand, the height of the flame being due to methane, of which such gas contains about 35 to 40 per cent. If, however, car-

buretted water-gas is taken, I have frequently seen a 2-inch flame emitting light equal to 22 candles value, this being (Lewes) due to its only containing 16 to 20 per cent. of methane. The influence of incombustible diluents on the illuminating power of ethylene has also been determined by Dr. P. F. Frankland, with the following results:

Diluent.	Percentage of ethylene.	Percentage of diluent.	Candle power per 5 cubic feet of gas.
Carbon dioxide .	93·68	6·32	55·52
	90·59	9·41	51·81
	89·03	10·97	49·98
	81·73	18·27	42·81
	70·75	29·25	33·23
	64·14	35·85	26·52
	52·94	47·06	14·72
	45·61	54·39	7·49
	40·00	60·00	0·00
	84·69	15·31	51·96
Nitrogen . . .	71·12	28·88	39·58
	59·93	40·07	29·64
	47·08	59·92	20·81
	36·24	63·76	11·82
	48·81	71·19	7·20
Oxygen	82·57	17·43	70·93
	80·67	19·33	72·53
	75·51	24·49	74·19
	68·50	31·50	71·17
	60·69	39·31	Explosion.
	79·68	20·32	54·45
Air	67·15	32·85	45·84
	55·92	44·08	37·16
	42·69	57·31	26·78
	33·91	66·09	16·22
	22·31	77·69	0·61
	13·31	86·69	Explosion.

“Moisture when present to the extent of 2 per cent. (the proportion present in coal-gas saturated at 20° C. and 760 mm.) in ethylene, reduces the illuminating power 3·6 per cent., or in coal-gas, 3·3 per cent. Of the inert, or non-combustible diluents therefore CO₂ is the most injurious and atmospheric air is the least harmful. Wurtz has determined the loss of light incidental to the addition of air to coal-gas, and he gives the following results :

Added air.	Percentage loss of light.
3·00	15·69
4·96	23·83
11·71	41·46
16·18	57·53
25·00	84·00

“The addition of oxygen to gas, rich in hydrocarbon causes an increase in the illuminating power up to a certain point. The temperature of the flame is increased by burning up the hydrogen of the hydrocarbons and rendering the carbon incandescent without diluting the flame with nitrogen to the extent which would have been necessary had air been used for the purpose. This effect is very noticeable in rich hydrocarbon gases of more than 50-candle power, but in a poor coal-gas of (say) 16 candles it is very difficult to get any increase in illuminating power, even a small percentage of oxygen overdoing the combustion.

“The effect of such gases as hydrogen and carbon monoxide is simply to dilute the flame, and by separating the molecules of the hydrocarbons to make them more difficult to decompose, while such bodies as CO₂, nitrogen, air, and water vapour, not only dilute, but also cool the flame, as they do not add to the heat by any action of their own, and have to be heated up to the same temperature as the flame itself.”

CHAPTER XXI.

THE ENRICHMENT OF COAL-GAS.

IN places where the illuminating power of the gas has to be kept above the quality obtainable from the ordinary common coal available in that particular district, it is necessary that the gas should be enriched by some means so as to enable it to reach the recognized standard, and up to a few years ago this enrichment was effected by mixing a certain proportion of cannel coal with the ordinary black or common coal; but, owing to various causes, cannel coal has lately so increased in price as to render its use almost prohibitory as an enriching agent, consequently gas companies have been compelled to find substitutes for cannel for the purpose of such enrichment, and these substitutes may be classed as "carburetted water-gas," "oil-gas," and the impregnation of the gas with the vapour of volatile hydrocarbons.

CARBURETTED WATER-GAS.

When steam acts upon carbon at a high temperature, the resulting action may be looked upon as yielding a mixture of equal volumes of hydrogen and carbon monoxide, both of which are inflammable but non-luminous gases. Owing to various reasons, however, this reaction does not occur in working on the "practical" scale, carbon dioxide to a certain extent being invariably present in the

“water-gas,” as it is termed, which on an average has the following composition:¹

	Per cent.
Hydrogen	48·31
Carbon monoxide	35·93
Carbon dioxide	4·25
Nitrogen	8·75
Methane	1·05
Sulphuretted hydrogen	1·20
Oxygen	0·51
	100·00

The ratio of CO and CO₂ present depends entirely upon the temperature of the generator and the kind of carbonaceous material employed. If a hard anthracite coal is employed, then a temperature can be attained at which there is practically no CO₂ formed, but with an ordinary generator, and a loose fuel like coke, a large percentage of that gas is generally produced. The sulphuretted hydrogen is derived from the sulphur, which is always present in gas-coke, and this latter impurity is also avoided by the employment of anthracite.

The nitrogen is the result of heating the fuel by an air blast, which leaves the pipes full of producer gas (nitrogen and carbon monoxide), which is carried over into the holder by the first portions of water-gas. Water-gas so produced is non-luminous.

The various forms of generator employed for the manufacture of water-gas are very numerous, and in some of these the gas is rendered luminous by the carburetting of the non-luminous water-gas with the vapours of certain oils either after or during the process of manufacture. The most successful of these carburetting processes can be

¹ Lewes, “Journal of Gas-lighting,” vol. lxiii, p. 385.

divided into two classes :—(1) Continuous processes in which the heat necessary to bring about the inter-action of the carbon and steam is obtained by performing the operation in retorts externally heated in a furnace; (2) intermittent processes, in which the carbon is first raised to incandescence by an air blast. When the air blast is cut off, steam is admitted until the temperature falls too low for the action, when the air is again admitted. The process, therefore, consists of alternate blows and runs.

Continuous processes have not as yet been a commercial success. The best of the intermittent processes, and the one which is mostly used in America, and has made the greatest progress in this country, is the Lowe. In this apparatus the fuel (coke or anthracite) is heated to incandescence by an air blast in what is known as the generator, which is lined with fire-bricks, and the resulting producer gas passes on to vessels known as the super-heaters, more air being admitted to insure its combustion. By this means the super-heater is raised to a high temperature. When the fuel and super-heater are at a sufficiently high temperature, the air blast is cut off, and steam blown through the generator, forming water-gas, and the latter then meets the oil necessary for its enrichment at the top of the first super-heater, which is known as the carburetter, and from thence passes on to the fixing chambers, where the hydrocarbons are rendered permanent gases. The chief advantage of this apparatus is that a low temperature can be used for fixing, owing to the large amount of surface for super-heating, which to a great extent does away with the deposition of carbon.

Plate V. shows a water-gas plant as erected by Messrs. R. and J. Dempster, Limited, of Manchester, the working of which may be briefly described as follows. B B are generator and carburetter, the generator being filled with anthracite, coal, or coke. The coke is lighted at the



E

F

[To face page 244.]

bottom of the generator, and blown with forced draught by the fan, A, until the coke is incandescent. The heat from the generator enters the carburetter at the top, and passes downwards, heating in its course the special bricks with which the carburetter is filled; the heat then enters the bottom of the super-heater, C, which is also filled with chequer brick-work, and the waste heat passes out at the top of the super-heater, and away up the chimney. The carburetter and super-heater being sufficiently heated, the forced draught to the generator is stopped, the waste heat outlet at the top of the super-heater is closed, and the gas-valve at the top of the oil super-heater, D, is opened.

Steam is now admitted under the grate bars of the generator, and in passing through the incandescent coke in the generator it becomes decomposed, the oxygen of the steam combining with the carbon of the fuel, forming CO and H, as previously explained.

In order to render the water-gas thus produced luminous, crude oil or petroleum is forced by means of a small pump fixed to the wall into the top of the carburetter in the form of a very fine spray. At this point it comes in contact with the water-gas, and is vaporized. There is thus a very intimate mixture of the particles of oil with the water-gas, and in passing through the heated bricks in B and C, the oil vapour becomes permanently gasified and incorporated with the water gas; the gas passes onwards through the oil super-heater, D, and forward through the condensers and scrubbers, E and F.

The process of gas-making continues until the heat in B is not sufficient to decompose the steam. When this stage is reached, the oil and steam-valves are closed, and the gas-valve is changed to its former position, and the process of raising the heat in the generator, carburetter, and super-heaters by the forced draught is repeated.

The art of making this gas is to keep the heat in the

super-heater, c, at the proper temperature, to permanently combine the oil vapours and the non-luminous water-gas, for if the heat is not sufficient, the two gases separate on cooling, whereas, if it is too great, lampblack is formed.

The most successful method for enriching gas by means of oil-gas is that devised by Mr. Young, of Clippens, known as the Peebles process.

The principle of Young's process is dependent upon the washing of the oil-gas, which is produced by retorting the oil at a moderate temperature by means of oil of the same description before retorting, by which it is freed from all condensable vapours, and only permanent gases are allowed to escape to the purifiers. No loss takes place, as the olefines and other fixed gases, which are absorbed to a considerable extent by the oil during the washing of the gas, are again driven out by the action of heat during the retorting. The apparatus consists of two cast-iron retorts, about 10 feet in length, and set so as to have a downward slope to the back. The retorts are fitted with doors and ascension pipes in the usual manner, but in each door a small test cock is fixed, by opening which the colour of the gas can be seen. This should be of the palest lemon, as when any darker colour or approach to brown is produced, then tar is deposited.

The oil is admitted by small cocks about 2 feet up the ascension pipe, and falls down, meeting the stream of ascending gas, on to steel plates which extend to a distance of about 3 feet into the retort, so as, in a great measure, to prevent the direct impact of the oil on to the bottom of the retort. The temperature is kept about 1,400° to 1,600° F.

After passing up the ascension pipes, the gas flows to the hydraulic main, which is situated at the back of the retort bench; it then passes through a coil of condensing pipes, and so on to the scrubber. The oil cistern is situated

at the top of the scrubber, and the supply pipe from it is so arranged that the oil can be made to flow into one or all of the sections, as in cold weather the gas needs less scrubbing than in hot.

After passing through the scrubber, the oil is led along the bottom of the horizontal condensers and into the hydraulic main. It then passes into a small cistern containing a float, which is in connection with an indicator close by the taps which regulate the oil supply, so that the supply from the cistern can be regulated in such a way as to insure a constant rate of flow. In this way the oil passing to the retort is always flowing in an opposite direction to the gas. The oil generally employed in Young's process is what is known as "blue oil," having on an average a specific gravity of about .850.

Each retort makes 500 cubic feet of gas per hour, and $5\frac{1}{2}$ cwt. of a very dense graphitic coke is left in the retort for each ton of oil decomposed. This coke collects near the back of the retort, and can be readily removed.

Plate VI. shows a Peebles plant, as erected by Messrs. R. and J. Dempster, Limited, of Manchester.

The most successful method of impregnating gas with the vapours of volatile hydrocarbons, suitable for dealing with large volumes of gas, is that of Messrs. Maxim and Clark, and which at the present time is in extensive operation. Attempts had previously been made to carburet gas by means of the vapours of volatile hydrocarbons, but these former efforts were not successful, the great difficulty experienced arising from the fact that all the commercial samples of naphtha are mixtures of various hydrocarbons, each having their own boiling point, and, as a result, they give up their more volatile constituents very freely at the beginning, while the amount rapidly diminishes as the boiling point of the residue becomes higher. The increase of evaporation with the increase of temperature further

aggravated matters. Now, these defects are not so apparent when gas is carburetted in bulk, as the gas to a certain extent mixes in the gas-holder by diffusion, and a fairly even illuminating power is the result.

The Maxim-Clark process not only does away with the difficulties previously alluded to, but carburets the gas used in bulk, so that each portion of the gas obtains its proper share of hydrocarbon.

For small installations, the apparatus consists of a circular copper retort, which is kept automatically filled to a fixed level with gasoline from a reservoir outside the building. The retort is jacketed, and steam or hot water is passed round it, which volatilizes the gasoline. This passes over baffle plates in the top of the retort, and then through an automatic regulator into a small holder sealed with mercury. The gas to be carburetted has to pass through this holder, and as it does so the gasoline vapour is supplied to it in the following manner. The holder works on a vertical spindle, which passes down the tube into the gasoline retort, and is so arranged that, when the holder is grounded, *i.e.*, when no gas is passing through, the opening is closed, and no gasoline can pass into the holder. As gas is admitted, so the holder rises and lifts the spindle with it, allowing the gasoline vapour to rush up through grooves cut in the bottom of it, which increase in size the higher the spindle is drawn, and so allow more gasoline to pass into the holder the more gas passes through.

CHAPTER XXII.

THE MANUFACTURE OF SULPHATE OF AMMONIA.

THE operation of manufacturing sulphate of ammonia essentially consists in driving off the gaseous ammonia (NH_3) contained in the ammoniacal liquor, and neutralizing the same with sulphuric acid (H_2SO_4) as per the following equation $2\text{NH}_3 + \text{H}_2\text{SO}_4 = (\text{NH}_4)_2\text{SO}_4$.

The process of making sulphate of ammonia from ammoniacal liquor is a very simple one, and the improved apparatus which has been introduced to gas-works during the last few years has further helped to make the manufacture of this product still more easy.

In small gas-works, where steam is not available, an under-fired still or boiler is used for the purpose of disengaging the ammonia from the liquor, but in larger works this method is not to be recommended, owing to the loss of fuel, and the disadvantage of liberating suddenly large volumes of sulphuretted hydrogen and other foul gases from the ammoniacal liquor when this reaches nearly to boiling point; the sudden liberation of these gases makes them difficult to deal with in order to avoid nuisance. The modern system is to use a continuous still, that is, to have the liquor always running in and out, the ammonia being taken out during its passage through the still.

Plate VII. shows a plan and elevation of a plant for making sulphate of ammonia on the continuous system, designed by Messrs. R. and J. Dempster, of Newton Heath, Manchester,

who have acquired a well-earned reputation for work of this description. In this form of plant the heat required to drive off the ammonia is obtained from steam which is introduced at the bottom of the still as shown.

The ammoniacal liquor is first pumped into an overhead tank, and from thence flows through what is termed a super-heater, or economizer. Here the hot foul gases from the saturator pass through the apparatus in an opposite direction, heating the cold liquor to boiling point, at the same time cooling the hot gases ready for the condenser and purifier.

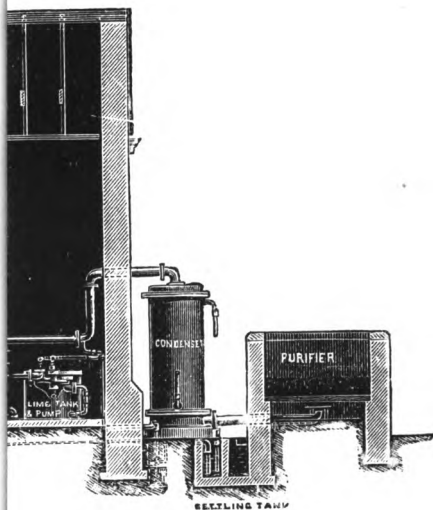
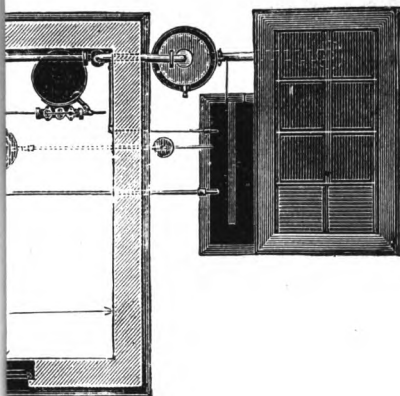
These gases can be purified in the ordinary way by oxide of iron, or they can be taken to a Claus kiln where the sulphur can be recovered in a pure form.

From the super-heater the liquor passes to the top of the main still, which is composed of a number of trays. These trays are perforated with holes, having flanges projecting upwards so as to secure a depth of about two and a half inches of liquid which is made to travel in a sinuous direction over each tray. These holes are covered with inverted troughs, serrated along their lower edges. Steam is admitted at the bottom of the still, and in its ascent boils up the liquor descending from tray to tray, and liberates the ammonia from the liquor, which is kept in a state of constant vibration.

Cream of lime is pumped into the bottom compartment of the main still from the lime mixer and pump shown in the corner of the sulphate house.

This is thoroughly mixed with the liquor which then flows through the secondary still where it is again treated to the vibrating action of steam and the whole of the fixed ammonia is in this way liberated.

The effluent liquid then passes automatically through a deep syphon pot without the intervention of valves, etc. In some cases the waste heat from this liquor is utilized



[To face page 250.]

by means of special apparatus to heat the cold water for steam boilers. Sulphuric acid is delivered into an overhead acid tank, and by means of suitable pipe and tap is led to the saturator. Here the ammonia gas, coming from the top of the still, is intimately mixed with the acid which, in a short time, begins to precipitate a salt in the form of sulphate of ammonia. The resulting salt is then fished out by means of ladles or steam elevators on to the drainer, which is constructed so that the liquid can run back into the saturator.

When the sulphate is sufficiently dry, it is thrown into the sulphate store which is constructed so that any further drainings will flow to the mother liquor well.

The mother liquor is used up again in the saturator.

APPENDIX.

THE REFEREES' SULPHUR TEST.

THE apparatus employed in this test is shewn in Fig. 64, and consists of a Bunsen burner A, with steatite top in which the gas to be tested is burnt, the burner being mounted on a short cylindrical stand, provided with a series of holes for the admission of air, and having on its upper surface a deep circular channel or groove, in order to receive the wide end of the glass trumpet-shaped tube B, which is connected to a glass cylinder C, filled with marbles and having a glass chimney tube E, at the top, for the purpose of affording a vent for the uncondensable vapours, and also to create a draught for the necessary air required. The inlet of the burner is connected to the outlet of an experimental meter capable of automatically shutting off the gas when ten cubic feet have been burnt. The apparatus is used in the following manner. The stem of the burner is surrounded with pieces of sesqui-carbonate of ammonia. The burner is then lit, and when the index of the meter is close to zero, the trumpet tube is placed in position on its stand, and its narrow end connected to the tubulure of the condenser, the long chimney tube being simultaneously attached to the top of the condenser. The burner is to be regulated to consume half a cubic foot per hour, so that it will take twenty hours to make a test; at the expiration of which time the meter will automatically cut off the supply of gas to the burner. After each testing, the vessel placed

underneath the condenser to receive the products of combustion is to be emptied into a measuring cylinder, and then replaced to receive the washings of the condenser. The trumpet tube is next removed and well washed out, the resulting washings being added to the contents of the measuring cylinder. The condenser is then treated with

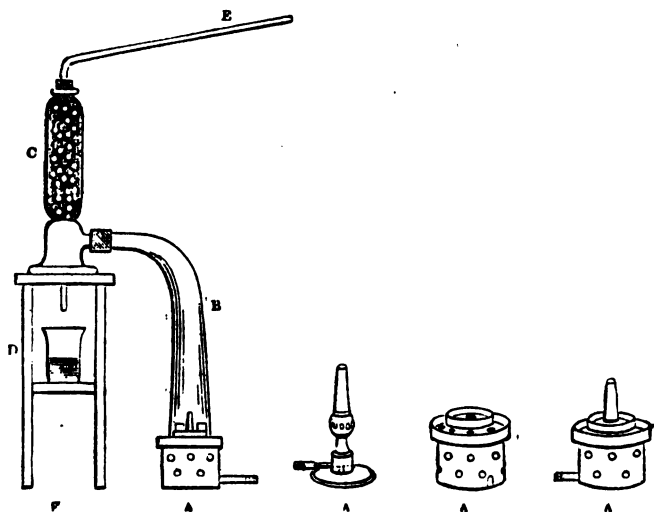


FIG. 64.

forty or fifty c.c. of distilled water, and these washings also added to the previous contents of the measuring cylinder; after which the whole of the liquid in the cylinder is well mixed and then divided into two equal parts, one portion being reserved for future reference if required. The remaining half of the liquid is now placed in a glass beaker, covered with a large watch glass, acidified with hydrochloric acid, and then gently raised to the boiling point. An excess of a solution of chloride of barium is then added

and the boiling continued for five minutes. The beaker and its contents are then allowed to stand until the barium sulphate settles at the bottom of the beaker, after which as much as possible of the clear liquid is poured on to a Swedish filter paper, and after this has passed through, the remaining liquid and barium sulphate are similarly treated, the contents of the filter being well washed with hot distilled water, until a small quantity of the final washings

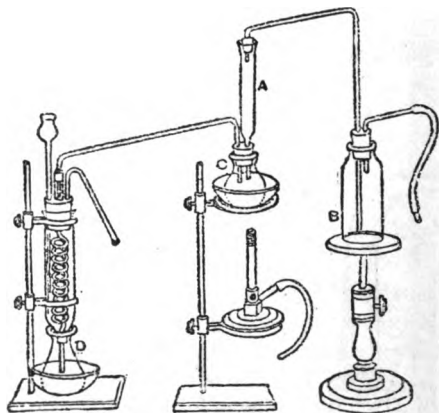


FIG. 65.

remain clear on adding a drop of a solution of nitrate of silver. The filter and its contents are then dried, and transferred into a weighed platinum crucible, which is gradually heated to redness until no black particles remain; it is then allowed to cool, and when nearly cold, placed in a desiccator over strong sulphuric acid and weighed again. The difference between the first and second weighings of the crucible will give the number of grains of barium sulphate. This weight multiplied by eleven and divided by four will give the number of grains of sulphur in 100 cubic

fect of the gas, this result being further corrected for any divergence of the temperature and pressure of the gas from the normal 60° F. and 30·0" Bar., or in other words the volume of gas burnt must be corrected to 60° F. and 30·0" Bar., and a corresponding proportion be made for any divergence from ten cubic feet at standard temperature and pressure.

SPENT OXIDE OF IRON TEST.

The amount of free sulphur in spent oxide of iron is arrived at by means of the apparatus shown in Fig. 65, the method of procedure being as follows.

Weigh 100 grains of the material, dry at a temperature of 100° C. and repeatedly weigh until a constant weight is obtained, so as to arrive at the percentage of moisture: then place the dried substance in A, which is packed at the bottom with a plug of cotton wool in order to serve as a filter.

A quantity of carbon bisulphide (CS_2) is then blown from the bottle B into A on top of the spent oxide, through which it percolates dissolving out the sulphur, the resulting solution finding its way by gravitation into the flask C, the latter being placed in a water bath which is heated so as to vapourize the carbon bisulphide, the vapour thus driven off, travelling through the connecting tube into the condenser, from whence it is recovered in the flask D (under water) ready for another experiment.

The sulphur is left in the tared flask attached to A, and when all the bisulphide has been driven off, on re-weighing the flask the quantity of sulphur in the 100 grains of oxide taken for experiment will be shown, and this figure will also express the percentage of sulphur on the "wet" basis.

SPECIMEN EXAMINATION PAPERS OF THE
CITY AND GUILDS OF LONDON INSTI-
TUTE IN GAS MANUFACTURE.

Wednesday, May 2nd, 1894. 7 to 10.

INSTRUCTIONS.

The Candidate must confine himself to one grade only, the Ordinary or Honours, and must state at the top of his paper of answers which grade he has selected. He must *not* answer questions in more than one grade.

If he has already passed in this subject, in the first class of the Ordinary Grade, he must select his questions from those of the Honours Grade.

The number of the question must be placed before the answer in the worked paper.

Three hours allowed for this paper.

The maximum number of marks obtainable is affixed to each question.

ORDINARY GRADE.

1. What do you understand by carbonization, and how is it conducted? (35 marks.)
2. Explain the conditions which are essential to good carbonization. (35.)
3. How are tar and ammoniacal liquor produced? (25.)
4. In what way is lime employed for the purification of gas? and explain its action. (30.)

5. What is meant by "8-oz. liquor"? (25.)
6. Describe the ordinary tests for ascertaining the purity of gas. (30.)
7. Describe the method of determining the illuminating power of gas. (30.)
8. Give a sketch of the Referees' sulphur test, and explain its use. (30.)
9. How is condensation usually effected? (30.)
10. What is a syphon or receiver, and under what circumstances is it necessary to use one? (30.)

HONOURS GRADE.

1. What is the proportion of gaseous products yielded by ordinary gas coal, and of what does it chiefly consist? (35 marks.)
2. Give a sectional elevation of the side of a purifier, and explain the reason for a determinate depth of water lute. (30.)
3. How may the presence of nitrogen in coal-gas be accounted for, and what is its effect upon the illuminating power? (35.)
4. Explain the difference between a puddled and a rendered tank, and state how the water-pressure is exerted in each case. (30.)
5. Describe any method or system by which hand labour in the retort-house may be reduced or dispensed with. (30.)
6. What is the Orsat-Muencke apparatus? Explain its use. (30.)
7. Explain the action of a modern gas-retort furnace, as illustrating the principles of economical combustion. (30.)
8. Why is it usual to free the gas from ammonia before it enters the purifiers? (25.)

9. Describe the process for the manufacture of sulphate of ammonia from gas liquor. (30.)

10. Describe a means for obtaining the highest illuminating value from coal-gas. (25.)

GAS MANUFACTURE.

May 1st, 1895.

ORDINARY GRADE.

1. Describe the process of carbonization, and give a sketch and description of a through clay retort.

2. What process immediately follows carbonization? how is it effected, and with what results?

3. What is the usual treatment of coal-gas for the removal of ammonia?

4. Enumerate the chief impurities contained in crude gas, and state how their presence may be detected.

5. Describe a method of freeing gas from sulphuretted hydrogen.

6. What is the use of the exhaustor?

7. How is the illuminating power of gas ascertained?

8. Of what service is the inferential jet photometer?

9. How would you test spent oxide for sulphur?

10. For what purposes are the station meter and governor employed in a gas-works, and how is the latter regulated?

HONOURS GRADE.

1. Describe the principles of the chief methods of heating gas-retorts.

2. Give an outline sketch (elevation) and description of a setting of eight retorts with fittings.

3. What kinds of coal are most valuable for gas-making and why?

4. Give a sketch (plan, elevation, and section) and description of a purifier, fitted with three tiers of sieves.

5. In what way would you estimate the quantity of ammonia, sulphuretted hydrogen, and carbonic acid in coal gas?

6. Give a description, with outline sketch, of an untrussed two-lift gas-holder and puddle-tank, and explain the difference between the latter and a rendered tank.

7. Describe a process for manufacturing sulphate of ammonia from ammoniacal liquor, pointing out what precautions should be taken in order to prevent nuisance.

8. Describe some system of stoking-machinery, and state what advantages it may have over hand labour.

9. Describe some method of enriching gas other than by means of cannel.

10. What is the difference between a flat-flame burner and an Argand? In what respects do these differ from an incandescent burner, and what advantages can be claimed for each?

INDEX.

- Acetylene, 236.
- Air condenser, 71.
- Ammonia, amount of, in crude gas, 103.
method of eliminating, 92-108.
properties of, 87.
reasons for eliminating, 87.
sulphate, 249.
test for, 127.
- Analysis of coal, 11.
gas, 235.
- Anderson's exhauster, 78.
washer, 94.
washer-scrubber, 106.
- Annular condenser, 72.
- Anthracite coal, 6.
- Argand burner, 222.
- Ascension pipes, 35.
stoppages in, 42.
- Ash in coal, 12.
- Ash pan, 31.
- Automatic pressure changer,
Cowan's, 182.
- Bar photometer, to graduate, 160.
- Batswing burner, 220.
- Battery condenser, 73.
- Beale's exhauster, 79.
- Bisulphide of carbon, properties
of, 87.
elimination from gas, 121-126.
- Bituminous coals, 7.
- Braddock's station governor, 178.
- Bray's burners, 221.
- Buckstaves for retort bench, 20.
- Bunsen photometer, 158.
- Burners, gas, description of, 217-226.
- Bye-pass mains, 193.
- Caking coal, 7.
- Calcium sulphide, formation of,
119, 121.
- Candle, standard sperm, 164, 165.
balance, 164.
corrections for consumption of,
167-168.
- Cannel coal, 7.
- Carbon, deposition of in retorts,
34.
- Carbonic acid, properties of, 86.
elimination of, 118.
test for, 128.
- Carbonization, description of, 14.
fuel required for, 30.
- Carburetted gas, 242-243.
- Cast-iron retorts, 16.
tanks, 144.
- Changer, Cowan's automatic
pressure, 182.
- Cherry coal, 7.
- Clay retorts, 16.

- Clinker, 31.
 Coal, ash in, 12.
 brown, or lignite, 6.
 caking, 7.
 descriptions used in gas-making, 7.
 formation of, 4.
 parrot or cannel, 7.
 splint, 7.
 sulphur in, 12.
 Coke, amount required for carbonizing, 30.
 Compensating meter, Warner and Cowan's, 207.
 Composition of purified gas, 235.
 Concrete tanks, 143.
 Condensation, description of, 69.
 Condensers, annular atmospheric, 72.
 area required, 75.
 battery, 73.
 horizontal atmospherical, 71.
 Livesey water, 74.
 Morris and Cutler water, 74.
 vertical, 71.
 Corrections for temperature and pressure, 227.
 Cowan's governor, 180.
 prepayment meter, 211.
 pressure changer, 182.
 Dempster's exhauster, 79.
 sulphate of ammonia plant, 249.
 water-gas apparatus, 244.
 Deposition of carbon in retorts, 34.
 Differential or district governor, 184.
 pressure gauge, 134.
 Dip-pipe, 37.
 Donkin's exhausters, 81.
 Dry meter, 208.
 D-shaped retorts, 17.
 Duration of retorts, clay, 18.
 iron, 18.
 Evans' photometer, 169.
 Examination papers, specimen, 252.
 Exhauster, the use of, 77.
 advantages of using, 78.
 Anderson's, 78.
 Dempster's, 79.
 Donkin's, 81.
 Gwynne's, 80.
 Jones's, 78.
 Laidlaw's, 78.
 Methven's, 78.
 Waller's, 82.
 Fire-clay retorts, 16.
 Fishtail burners, 220.
 Flange joints, 192.
 Flat-frame burners, 220.
 Foulis - Arrol stoking machine, 47.
 Fuel required for carbonizing, 30.
 Furnace, ordinary, 25.
 generator, 26.
 regenerative, 27.
 Gadd's system of guide framing, 150.
 Gas-holder, capacity of, to find, 151.
 pressure of, to ascertain, 151.
 rise allowed in crown, 147.
 single lift, 146.
 telescopic, 148.
 trussed and untrussed roof, 147.
 Gas-holder tanks, annular, 139.
 brick and puddle, 141.
 cast-iron, 144.
 concrete, 143.

- Gas meter, compensating, 206.
dry, 208.
prepayment, 211.
Warner and Cowan's, 206.
wet, 203.
- Gauge, pressure, 133.
differential, 134.
King's, 135.
Thomas's, 135.
- Generator furnace, 27.
- Governor, district, 184.
exhauster, 84.
station, 175.
station, Braddock's, 178.
station, Cowan's, 180.
station, Hunt's, 179.
- Hartley's candle balance, 164.
- Holman's eccentric fastener for
retort lids, 36.
- Horizontal condenser, 71.
- Hunt's governor, 179.
- Hydraulic main, 37.
- Illuminating power tested by
Bunsen photometer, 164.
power by jet photometer, 131.
- Impurities in crude gas, 86.
- Incandescent burner, 225.
- Iron retorts, 16.
- Jet photometer, Lowe's inferential,
131.
- Jointing mains, 186.
- Jones's exhauster, 78.
- Kirkham, Hulett, and Chandler's
washer-scrubber, 104.
- Laidlaw's exhauster, 78.
- Lead papers, to prepare, 128.
- Letheby - Bunsen photometer,
161.
- Lids, retort, luting for, 35.
Morton's self-sealing, 36.
- Lignite, 6.
- Lime for purifying, 118.
- Lime-water, to prepare, 128.
- Litmus papers, to prepare, 128.
- Livesey's washer, 95.
- London gas, composition of, 235.
- Luting for retort lids, 35.
- Main laying, 185.
- Main pipes, casting, 185.
jointing of, 186.
laying of, 186.
testing of, 191.
- Maxim-Clarke system, 248.
- Meters, compensating, 206.
dry, 208.
prepayment, 213.
station, 215.
Warner and Cowan's, 207.
wet, 203.
- Methven's exhauster, 78.
screen, 172.
- Morton's self-sealing retort lid,
36.
- Mouthpiece, retort, 35.
- Naphthalene, remarks on, 199.
- Nitrogen in coal, 15.
- Oxide of iron, 114.
spent, 115.
- Oxygen in coal, 11.
gas, 233.
uses of, in purification, 122.
- Parrot coal, 7.
- Peebles' oil-gas process, 246.

- Pentane, Harcourt's, standard of light, 173.
 Photometer, Bunsen's, 158-161.
 Evans, 160.
 Letheby-Bunsen, 161.
 Lowe's jet, 129.
 Pipes, ascension, stoppages in, 42.
 main, 186.
 service, 198.
 Prepayment gas meter, Cowan's, 211.
 Pressure changer, Cowan's automatic, 182.
 variation of, with level, 183.
 Pressure gauge, 133.
 differential, 134.
 King's, 135.
 Thomas's, 135.
 register, 136.
 Pressure and temperature, method of correcting for, 227.
 Products, effect of temperature upon residual, 60.
 Products from Newcastle coal, 66.
 Puddle and brick gas-holder tank, 141.
 Purification, elimination of ammonia, 93.
 carbonic acid, 119.
 sulphuretted hydrogen, 116.
 sulphur compounds, 120.
 tar, 68.
 Purifiers, centre valves for, 117.
 construction of, 111.
 covers, 112.
 covers, raising, 112.
 lime, thickness of in, 118.
 oxide of iron in, 117.
 valves for changing, 117.
 Rake, backing, 32.
 drawing, 34.
 Regenerative burners, 223.
 furnace, 29.
 Register, pressure and exhaust 136.
 Residuals, effects of temperature upon, 60.
 Retorts, cast-iron, 16.
 clay, 16.
 different shapes of, 16.
 dimensions of, 18.
 duration of clay and iron, 18.
 setting of, 22.
 single, 18.
 through, 18.
 Retort-house tools, description of, 34.
 setting, description of, 22.
 Rotary and reciprocating exhausters, 78.
 Scoop for charging retorts, 32.
 Scrubber tower, description of, 99.
 Scurfing retorts, 34.
 Service pipes, 195.
 Specimen examination papers, 252.
 Spent oxide of iron, 115.
 Sperm candle, the standard, 165.
 Standards of light, Dibdin's, 173.
 Harcourt's, 173.
 Methven's, 172.
 Station governor, 175.
 Braddock's, 178.
 Cowan's, 180.
 Hunt's, 179.
 meter, 215.
 Sulphate of ammonia, manufacture of, 249.
 Sulphur compounds, elimination of, 120.
 Sulphuretted hydrogen, 116.

- Tanks, annular, 139.
brick and puddle, 141.
cast-iron, 144.
concrete, 143.
- Tar, elimination of, 67.
- Telescopic gas-holder, 148.
- Temperature, effects of, on gas, 52.
on residuals, 60.
- Temperature and pressure, mode of correcting for, 227.
- Test for detection of ammonia in gas, 127.
carbonic acid in gas, 128.
sulphuretted hydrogen, 128.
- Through retorts, 18.
- Tools, retort-house, 34.
- Tower scrubber, 99.
- Turmeric paper, to prepare, 127.
- Turned and bored joints, 188.
- Valves, centre, 117.
disc, 194.
- Waller's exhauster, 82.
- Warner and Cowan's meter, 207.
- Washer, Anderson's, 94.
Livesey's, 95.
Walker's, 98.
- Water and air, comparison of, as cooling agents, 74.
- Weldon mud, 123.
- West's stoking machinery, 43.
- Wet meter, 203.
- Wright's photometrical apparatus, 161.
- Wrought-iron main pipes, 185.
service pipes, 195.
- Young's oil-gas process, 246.

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